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Sludge Processing, Transportation and Disposal/Resource Recovery A Planning Perspective

Engineering-Science, Inc.

Prepared For
Environmental Protection Agency

December 1975

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WATER QUALITY MANAGEMENT GUIDANCE

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SLUDGE PROCESSING, TRANSPORTATION AND DISPOSAL/RESOURCE RECOVERY: A PLANNING PERSPECTIVE

DECEMBER 1975

ENVIRONMENTAL PROTECTION AGENCY
WATER PLANNING DIVISION
WASHINGTON, D.C. 20460

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Residual wastes generated in municipal wastewater treatment plants were characterized. Handling and treatment processes for the residual wastes are discussed and evaluated in light of qualitatative and quantitative changes to the residual wastes. Liquid, gaseous, and solid sidestreams produced in residual waste treatment were evaluated and rail, pipeline, barge, and truck transport of residual wastes were analyzed.

Environmental, operational, and institutional constraints to the use of ocean disposal, lagoons, sanitary landfills, sludge recycling, and land reclamation were presented.

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ABSTRACT

A methodology was developed in this report for use in the evaluation of alternatives for the ultimate disposal of residual wastes generated in municipal wastewater treatment plants. This methodology considered technical, economic, social, and institutional factors pertinent to a thorough review of alternatives.

Residual wastes generated in municipal wastewater treatment plants were characterized. Handling and treatment processes for the residual wastes were discussed and evaluated in light of qualitative and quantitative changes to the residual wastes. Liquid, gaseous, and solid sidestreams produced in residual waste treatment were evaluated and rail, pipeline, barge, and truck transport of residual wastes were analyzed.

Environmental, operational, and institutional constraints to the use of ocean disposal, lagoons, sanitary landfills, sludge recycling, and land reclamation were presented.

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CHAPTER I

INTRODUCTION

BACKGROUND

A review of the Federal Water Pollution Control Act Amendments of 1972 (the Act) and the associated legislative history clearly indicates the Congressional intent to eliminate as much as possible pollutant discharges to receiving components of the environment. The basic waste treatment process consists of separating contaminants in a way that is acceptable to local, State, and Federal regulatory agencies. Proper ultimate disposal or reuse of residual wastes is essential so that usable environmental components such as surface or ground waters will not be needlessly contaminated and that pollutants are not continuously and directly recycled into water supplies, food chains, and other cycles.

At the present time, solids handling and other ultimate disposal operations are probably the most troublesome problems in treatment plant operations, partly because they have had the least attention. The problem is becoming more critical since residual waste volumes are increasing with higher treatment efficiencies and because the physical-chemical sludges and other residual wastes from tertiary treatment operations are more difficult to handle than some of the common biological sludges.

The basic approaches embodied in the Act require pragmatic and logical steps to identify and control pollution sources, including:

(1) regional planning and management of the Nation's waters which will eventually identify all point and non-point sources of pollution within a given region, and establish effluent limitations on these sources of pollution;

(2) delegation of the permit programs to approved State programs after guidelines have been prepared by the Federal Government; and

(3) control programs to determine compliance with the effluent limitations and commencement of civil and criminal proceedings against violators.

OBJECTIVES

Regional planning and management processes to be undertaken in the 208 planning process must be as inclusive as physically possible, both with respect to known types of pollution and the limitations of treatment processes for removing various pollutants. In addition, Sections 201(d), 201(e), 201(f) of the Act specifically encourage resource utilization and resource recycling. Within this encouragement lies the intent that planning processes carried out in fulfillment of Sections 201, 208, and 303 recognize and promote, where possible, areawide implementation concepts of residual waste management.

Under subsections (J) and (K) of Section 208(b)(2) of the Act, 208 planning and management agencies must address "a process to control the disposition of all residual waste generated in such area which could affect water quality; and a process to control the disposal of pollutants on land or in subsurface excavations within such area to protect ground and surface water quality." In addition, Section 201(d)(4) of the Act requires in 201 facilities planning consideration of "the ultimate disposal of sludge in a manner that will not result in environmental hazards." It therefore is also the concern of 208 planning agencies that facilities plans already made and either presently under construction or proposed for construction within the twenty-year 208 planning time framework be incorporated in the overall 208 plan which is to include residual waste disposal control.

The objectives of 208 planning in terms of residual waste management and control must then consider not only the disposal of residual wastes in an environmentally acceptable manner but also the utilization of these wastes as a resource where possible.

PURPOSE

The purpose of this report is to provide information to 208 planning agencies regarding the sources, characteristics, treatment methods, transportation modes, and ultimate disposal processes available for use in the planning area. Information is also provided on ways in which residual wastes may be utilized or recycled as a resource. This information is provided in a manner conducive to its utility in the evaluation and formulation of alternative plans and the selection of the preferred plan under guidelines developed by the Environmental Protection Agency for use in the 208 planning and management process.

This report does not provide criteria for the construction grants program.

CHAPTER II

STUDY CONTEXT

INTRODUCTION

Within a 208 planning area there are a multitude of interacting constraints and criteria dealing with municipal wastewater treatment and the ultimate disposal or reuse of the resultant residuals. The 208 planning agency will be faced with numerous options of both approaching and conducting the required overall 208 plan development and the integration of the various sub-plans (i.e. wastewater treatment, non-point source controls, stormwater management, land use, etc.).

Residual waste management planning within the 208 effort must not only be coordinated with the other sub-plans, but it must also be aware of and responsive to other planning programs and present and proposed future activities within the 208 planning area. A major part of residual waste management planning must also consider such concerns as resource conservation (e.g. energy, materials, recycling), impacts upon socio-economic systems (e.g. transportation, public health), and implementation of planning programs (e.g. feasibility, performance, institutions).

A general perspective of residual waste planning is depicted in Figure II-1. The basic components of the planning process, shown in Figure II-1 as the blocked areas, have been discussed in this report document in light of their interrelationships one with the other as well as the various planning considerations mentioned above.

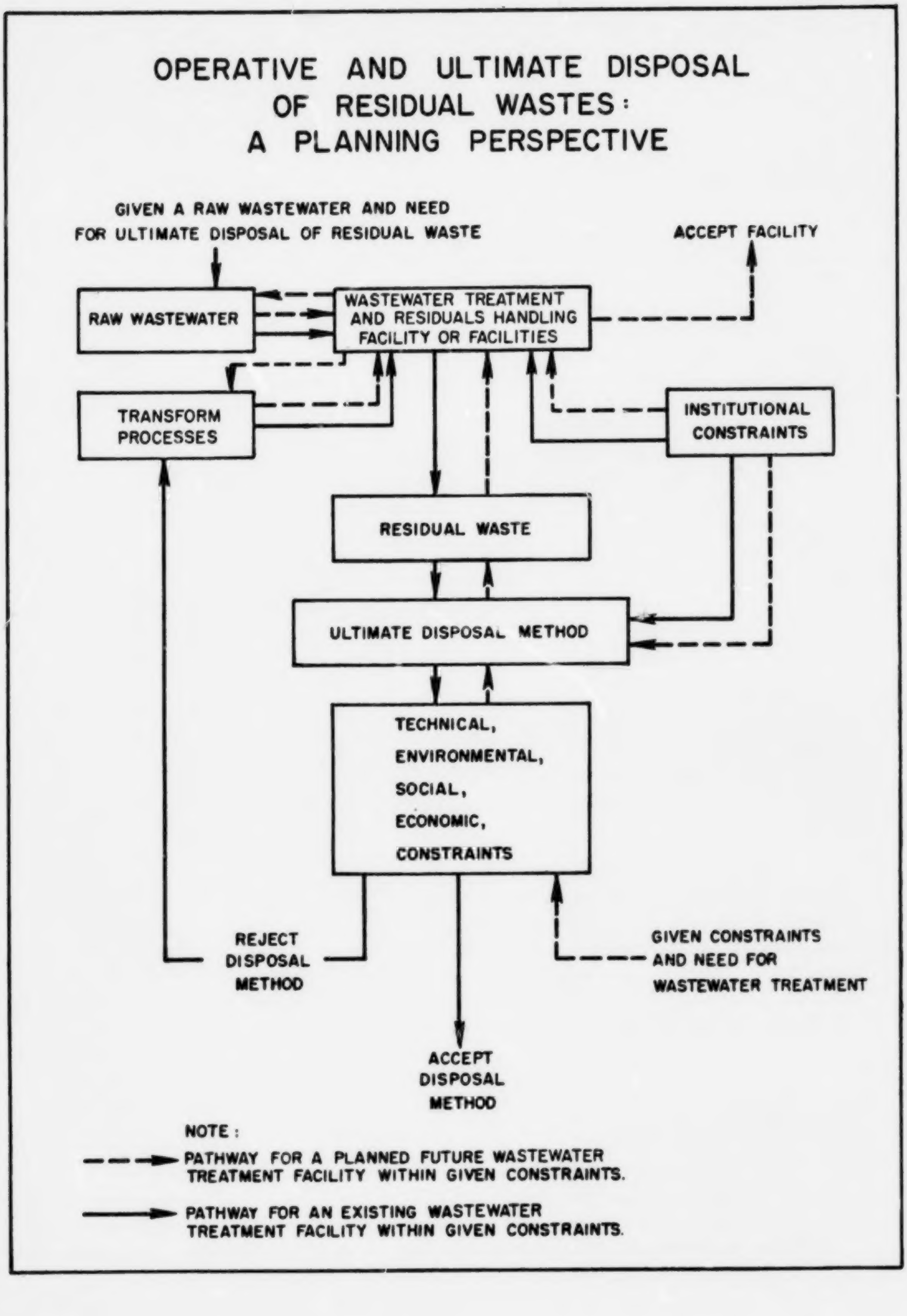
The following portions of this chapter are devoted to the overall understanding of this perspective and the utilization of this report document as a pragmatic approach to the development and evaluation of municipal wastewater treatment residuals generation, handling, transport, and ultimate disposal or reuse.

GENERAL PLANNING PERSPECTIVE

Implicit in the general planning perspective shown in Figure II-1 is the essence of two major, yet separate, starting points in the planning process. They are:

(1) given an existing wastewater treatment facility or facilities with the attendant residuals generation and processing, what are acceptable (i.e. capable of meeting various constraints) disposal or reuse options available for consideration and selection, or

FIGURE II-1



OPERATIVE AND ULTIMATE DISPOSAL OF RESIDUAL WASTES: A PLANNING PERSPECTIVE

GIVEN A RAW WASTEWATER AND NEED FOR ULTIMATE DISPOSAL OF RESIDUAL WASTE
ACCEPT FACILITY
RAW WASTEWATER
WASTEWATER TREATMENT AND RESIDUALS HANDLING FACILITY OR FACILITIES
TRANSFORM PROCESSES
INSTITUTIONAL CONSTRAINTS
RESIDUAL WASTE
ULTIMATE DISPOSAL METHOD
TECHNICAL, ENVIRONMENTAL, SOCIAL, ECONOMIC, CONSTRAINTS
REJECT DISPOSAL METHOD
GIVEN CONSTRAINTS AND NEED FOR WASTEWATER TREATMENT
ACCEPT DISPOSAL METHOD
NOTE:
PATHWAY FOR A PLANNED FUTURE WASTEWATER TREATMENT FACILITY WITHIN GIVEN CONSTRAINTS.
PATHWAY FOR AN EXISTING WASTEWATER TREATMENT FACILITY WITHIN GIVEN CONSTRAINTS.

(2) where wastewater treatment is needed and given natural and cultural constraints applicable in the planning area, what is the most suitable wastewater treatment facility available which allows the disposal or reuse of the resultant residuals in an acceptable option?

In the first situation (pathway) cited above, the existing wastewater treatment facility is generating a known quantity and quality of residual wastes. Federal, State, and local guidelines and regulations help define the ultimate residual waste disposal options available to that facility. These disposal options, by virtue of regulatory and environmental, social, and economic constraints, will then have restrictions as to the quantity and quality of residual wastes they can accept. By a comparison of the disposal methods' qualities and quantities of residual wastes they can handle with the known values from the wastewater treatment facility, the facility can either utilize the disposal methods available or further treat and transform the residual wastes to qualities and quantities amenable to the available disposal methods.

The second situation (pathway) is essentially an integration process. A planning area will have acceptable ultimate disposal methods, again constrained in quantities and qualities which they can handle by virtue of regulations and environmental, social, and economic factors. The choice of the type of wastewater facility processes will then be influenced by comparing predicted quantities and qualities of residual wastes from a variety of treatment processes to those of the acceptable and available ultimate disposal methods. In this case, the quantities and qualities of residual wastes from various wastewater treatment processes can be modified by both raw wastewater modification, such as industrial pretreatment, and by residual waste treatment and transformation processes.

Traditionally, the planning process for residual waste management has been the first situation; that is to select the least-costly disposal method after the wastewater treatment facility has been selected. However, a major effort of the 208 planning process is oriented to a more coordinated and comprehensive review including the assessment of residuals disposal on areas such as non-point source pollution and land use planning. The advantage of this integrative approach is that it allows for a more systematic cost-effective evaluation of the overall wastewater treatment problem which includes residuals management. This approach assures a more environmentally sound and cost-effective solution to the planning area which can then be integrated into all other planning activities within the area.

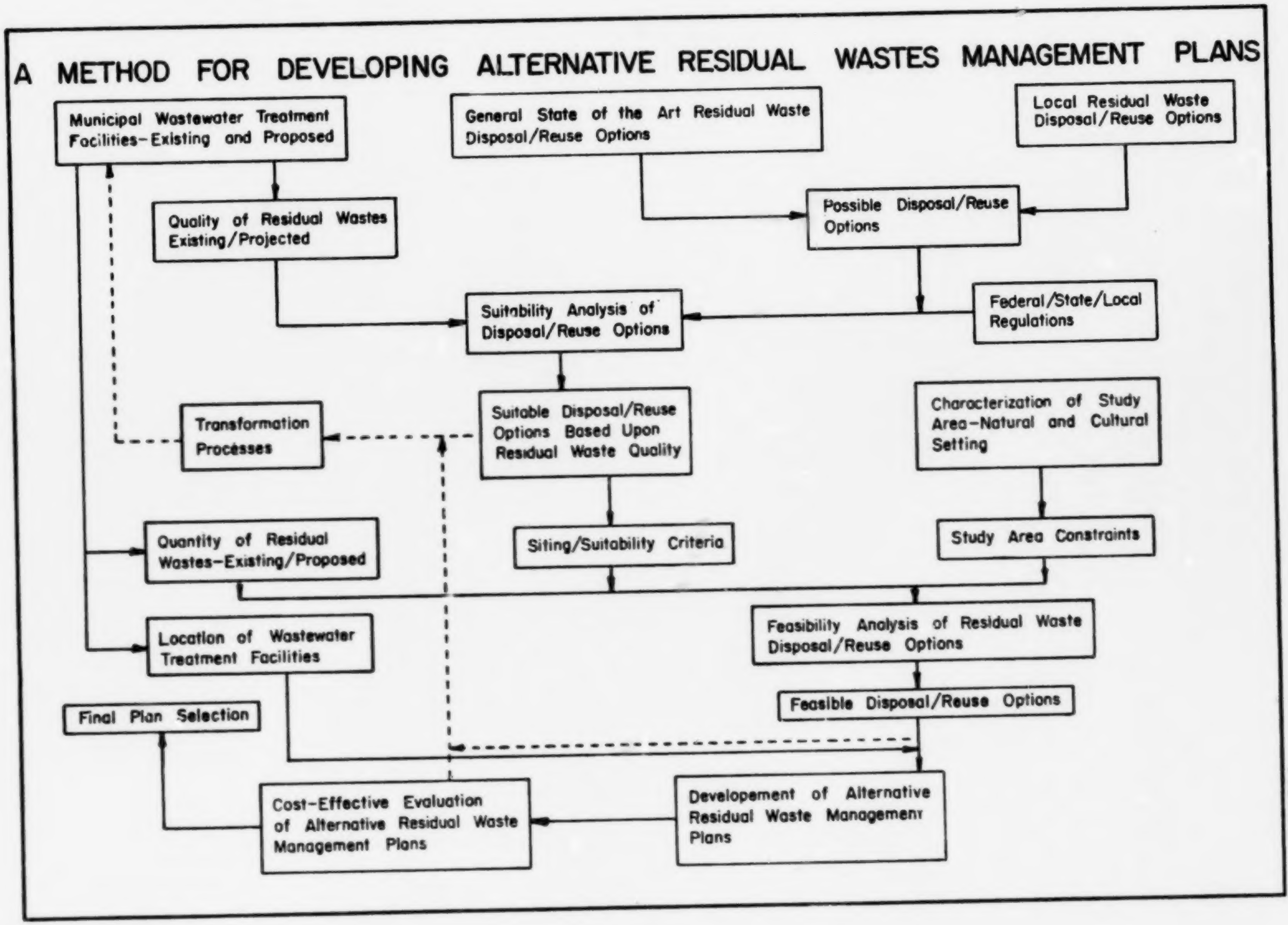
THE PLANNING APPROACH

Having identified the basic components involved in planning for residual waste disposal/reuse, it is essential to develop a systematic approach to delineate alternative residual waste management plans. This is particularly important because the number of components involved in the decision process and the large number of alternative elements within each component can lead to an unwieldly number of possible disposal alternatives. An additional consideration is the number and types of wastewater treatment plants to be considered which may require the use of several different disposal options within any one management plan. Therefore, it is imperative that residual waste management planning processes be formulated in such a manner as to clearly define the limits and constraints under which the development of alternative plans will be conducted and evaluated. Examples of limits or constraints which should be identified initially would be the desired level of aggregation of wastewater treatment plants (i.e., individual sets of alternatives for each facility or regional alternatives for several facilities) or the desirability/feasibility of residual waste disposal/reuse options altering wastewater facility process design of existing or proposed facilities. Without a clear definition of the planning goals and, possibly more important, the feasibility of the planning goals, the development of the residual waste management alternatives could become an academic exercise.

Figure II-2 is presented as an example method or approach for a residual waste management planning process. It is intended, primarily to show general study elements and their interrelationships. Information flows are broadly identified along with the types of information required as input to decision areas. [In addition, this figure is utilized to show the types of information to be found in this report.]

The following chapters of this report are intended to provide a convenient starting point for developing the information necessary in the residual waste management planning process. Chapter III describes in some detail the various wastewater treatment processes used and provides general information about sludge quantities and qualities generated from these processes. Chapter IV, similarly, describes the sludge handling processes used in wastewater treatment facilities and the changes in sludge quality and quantity that occur. In addition, general capital and O&M costs are also given for these processes. Chapter V presents the various sludge and residue transport mechanisms utilized along with some general cost information. Chapter VI describes in some detail the common and not-so-common ultimate disposal methods available. Areas discussed include operational characteristics, siting criteria, monitoring provisions, and general

FIGURE II-2


A METHOD FOR DEVELOPING ALTERNATIVE RESIDUAL WASTES MANAGEMENT PLANS

Municipal Wastewater Treatment Facilities-Existing and Proposed
General State of the Art Residual Waste Disposal/Reuse Options
Local Residual Waste Disposal/Reuse Options
Quality of Residual Wastes Existing/Projected
Possible Disposal/Reuse Options
Suitability Analysis of Disposal/Reuse Options
Federal/State/Local Regulations
Transformation Processes
Suitable Disposal/Reuse Options Based Upon Residual Waste Quality
Characterization of Study Area-Natural and Cultural Setting
Quantity of Residual Wastes-Existing/Proposed
Siting/Suitability Criteria
Study Area Constraints
Location of Wastewater Treatment Facilities
Feasibility Analysis of Residual Waste Disposal/Reuse Options
Final Plan Selection
Feasible Disposal/Reuse Options
Cost-Effective Evaluation of Alternative Residual Waste Management Plans
Developement of Alternative Residual Waste Managemenr Plans

costs. Chapter VII presents an alternative plan evaluation technique based on the cost-effective guidelines promulgated by EPA. Chapter VIII describes some non-structural controls available in controlling residual wastes problems and some general guidelines to consider in setting up a monitoring program for residual waste management facilities.

It must be recognized that the information presented in this document may, in some cases, be only of general utility and not directly applicable to the planning area under consideration (e.g. transportation costs, land application sludge loading rates, etc.). Where the desire of the 208 planning agency is to develop site-and area-specific information for inclusion in the final residual waste management plan selection, local data should be used when available. The data presented in this document would then be used to verify local data or as primary source information if local data were unavailable.

CHAPTER III

SOURCES AND CHARACTERISTICS OF MUNICIPAL WASTEWATER TREATMENT PLANT RESIDUALS

INTRODUCTION

As the United States moves toward the goals and policies described in Section 101 of the Federal Water Pollution Control Act Amendments of 1972, publicly-owned treatment works (POTW's) are required to meet by July 1, 1977, or July 1, 1978 (for new construction), secondary treatment as defined in the Federal Register (Ref. III-1). In addition, by Sections 201(g)(2)(A) and 301(b)(2)(B) of the Act, POTW's are to provide by July 1, 1983, the application of best practicable waste treatment technology.

The application of wastewater treatment technologies to meet these requirements is anticipated to generate substantial amounts of municipal wastewater treatment plant sludges which must be handled yearly as shown in Table III-1. Realizing that sludge handling absorbs 35 percent of the capital costs and 55 percent of the annual operation and maintenance costs of a wastewater treatment plant, these projected increases in sludge production will mean considerable expenditures of money (Ref. III-2). Every effort must be taken by 208 planning and management agencies to see that the expenditures necessary for sludge handling and disposal are made wisely.

TABLE III-1

TRENDS IN PRODUCTION OF MUNICIPAL WASTEWATER SLUDGE

Sludge Type	1972		1985	
	Population (million)	Dry tons** per year	Population (million)	Dry tons per year
Primary (0.12 lb/cap-da)*	145	3,170,000	170	3,720,000
Secondary (0.08 lb/cap-da)	101	1,480,000	170	2,480,000
Chemical (0.05 lb/cap-da)	10	91,000	50	455,000
TOTAL		4,741,000		6,655,000

* lb x 0.454 = kg
** ton x 0.908 = metric ton

Source: Ref. III-3

There are an estimated 21,118 publicly-owned treatment works of varying sizes in the United States using a variety of treatment and discharge processes (Ref. III-4). These treatment works are shown in Table III-2 by treatment process and location distribution. It has been noted that "most stream segments in urban-industrial areas undertaking 208 plans will be water-quality limited" (Ref. III-5). The import of this fact is that, of the close to nine thousand publicly-owned treatment works on water-quality limited segments, a potentially significant portion may have to provide treatment higher than secondary before 1977 to provide the necessary protection of water quality. This translates into greater volumes of sludge which must be handled prior to ultimate disposal.

TABLE III-2

ESTIMATED DISTRIBUTION OF PUBLICLY-OWNED TREATMENT WORKS

	Major Plants (1 MGD or more)			Minor Plants (1 MGD or less)		Total
	WQL[a]	EL[b]	EL-OO[c]	WQL	EL	
None	29	32	3	944	1,462	2,467
Primary	549	366	62	828	1,278	3,022
Pond	87	50	7	1,800	2,791	4,728
Trickling Filter	574	382	57	1,367	2,015	4,338
Activated Sludge	235	219	35	872	1,162	2,488
Extended Aeration	42	29	4	686	1,071	1,828
Secondary - Other	112	77	13	518	879	1,586
Land Disposal	5	3	--	58	91	157
Tertiary	42	30	4	169	263	504
TOTAL	1,676 (sic)	1,188	185	7,242	11,012	21,118 (sic)

a) Plants located on water-quality-limited segments.
b) Plants located on effluent-limited segments.
c) Plants located on effluent-limited segments with ocean outfalls.

Source: Ref. III-4

The following sections of this chapter will provide a general background as to the sources and characteristics of municipal wastewaters and modes of treatment. Reference will be made to many of the design manuals and guidelines prepared by the Environmental Protection Agency (EPA) so that planners may find more detailed explanations and examples helpful in the overall understanding of the integrated nature of the sludge disposal problems in their planning areas.

WASTEWATER CHARACTERISTICS

The nature of the physical, chemical, and biological characteristics of municipal wastewaters is basic to the understanding of facilities expected in 201 and 208 planning programs. The composition of raw sewage either anticipated in future growth or in the expansion of existing facilities depends upon the character of the municipal water supply, the industrial mix of the community, the proportion of commercial to residential development, and the nature of the residential community. The wastewater collection system, particularly the control infiltration and inflow (see Ref. III-6), will also influence the wastewater quality prior to treatment. As the wastewater quality impacts upon the choice of wastewater treatment, so too will it impact upon possible sludge disposal alternatives.

Table III-3 gives typical compositions of strong, medium, and weak domestic sewage. These typical compositions are average, not only in light of the above variables, but also because of variations in flows during the day, week, and month. Estimates of the components of total solids in the wastewater are given in Table III-4.

One area in which the 208 planning agency can directly affect wastewater volume and quality and thus indirectly affect sludge handling and disposal alternatives is that of pursuing programs to reduce domestic water consumption. Previous studies have been made in an attempt to typify the average household water requirements for a family of four (Ref. III-8). By using in combination such household devices as shallow trap toilets, flow control showers, one- and two-flush valves with toilets, and faucet aerators, a substantial water savings, on the order of 189 liters per day (50 gallons per day) per home, could be realized. These five devices are commercially available, relatively easy to install, and with proper minimum homeowner maintenance would provide substantial water savings to the homeowner without the necessity of more sophisticated and potentially unreliable systems. The potential reductions in water consumption would translate directly to reductions in water treatment plant sludges. Where these sludges may be discharged to the sewer system for treatment in the wastewater treatment plant or transported to a collection point for common handling and disposal with wastewater treatment sludges, the reduction of these water treatment sludges would directly impact the overall basin-wide sludge management alternatives available for consideration. Savings in wastewater flows could also impact upon the choice of wastewater treatment systems and hence upon sludge handling and disposal programs as well. These savings could be significant in light of data from the Environmental Protection Agency's 1973 "Needs" survey for municipal wastewater treatment facilities. This survey indicated that for 7605 reporting municipalities there was correspondingly a total wastewater flow of 6.7528×10^7 m^3/day (17,841 million gallons per day), twenty percent of which was attributed to industrial sources (Ref. III-9).

Pretreatment standards for industrial wastes discharging to publicly owned treatment works have been promulgated by EPA (Ref. III-10). Guidelines for pretreatment recognize that one of several factors to be evaluated is the "compatibility with the entire treatment works including sewers, pumping stations, and sludge handling and disposal" (Ref. III-11). Organic and

TABLE III-3

TYPICAL COMPOSITION OF DOMESTIC SEWAGE

(All values except settleable solids are expressed in mg/liter)

Constituent	Concentration		
	Strong	Medium	Weak
Solids, total	1,200	700	350
Dissolved, total	850	500	250
Fixed	525	300	145
Volatile	325	200	105
Suspended, total	350	200	100
Fixed	75	50	30
Volatile	275	150	70
Settleable solids (ml/liter)	20	10	5
Biochemical oxygen demand, 5-day, 20 C (BOD_5)	300	200	100
Total organic carbon (TOC)	300	200	100
Chemical oxygen demand (COD)	1,000	500	250
Nitrogen (total as N)	85	40	20
Organic	35	15	8
Free ammonia	50	25	12
Nitrites	0	0	0
Nitrates	0	0	0
Phosphorus (total as P)	20	10	6
Organic	5	3	2
Inorganic	15	7	4
Chlorides*	100	50	30
Alkalinity (as $CaCO_3$)	200	100	50
Grease	150	100	50

*Values should be increased by amount in carriage water.

Source: Ref. III-7

TABLE III-4

ESTIMATE OF THE COMPONENTS OF TOTAL SOLIDS IN WASTEWATER

Component	Dry weight, gpcd (grams per capita per day)
Water supplies and ground water, assumed to have little hardness	12.7
Feces (solids, 23%)	20.5
Urine (solids, 3.7%)	43.3
Toilet (including paper)	20.0
Sinks, baths, laundries, and other sources of domestic wash waters	86.5
Ground garbage	30.0
Water softeners	*
Total for domestic sewage from separate sewerage systems, excluding contribution from water softeners	213
Industrial wastes	200‡
Total for industrial and domestic wastes from separate sewerage systems	413
Storm water	25+
Total for industrial and domestic wastes	438

* Variable.
+ Will vary with the season.
‡ Will vary with the type and size of industries.

Source: Ref. III-7

inorganic compounds, both soluble and insoluble, discharged by industries into municipal wastewater treatment plants may create significant upsets in sludge digestion and handling processes (Ref. III-12). Proper consideration must therefore be given in the 208 planning activity either to correcting present difficulties in sludge handling due to industrial inputs or to using the guidelines mentioned above to insure no future problems. Monitoring of industrial waters can be done using techniques suggested by EPA (Ref. III-13).

WASTEWATER TREATMENT TECHNOLOGIES

Wastewater treatment technologies to achieve secondary and best practicable treatment have been suggested by the Environmental Protection

Agency (Ref. III-4). Additional guidance in the comparison selection of cost-effective wastewater treatment technologies is available (Refs. III-14, III-15, and III-16).

A manual has been prepared by EPA to assist in the performance evaluation of existing wastewater treatment plants (Ref. III-17). The 208 planning agencies and their staffs can utilize this manual in the evaluation of sludge handling problems and corrective measures to be taken in the operation and disposal of wastewater treatment sludges.

Upgrading of existing wastewater treatment facilities may be an integral part of the 208 plans. Guidance in this activity has been prepared by EPA (Ref. III-18). Additional supportive information and guidelines for facilities planning under Section 201 of the Act have also been prepared by EPA (Refs. III-19, III-20, III-21, III-22, and III-23).

The following sections discuss the wastewater treatment technologies commonly employed to meet requirements of treatment and discharge as presented in Reference III-4.

Primary Treatment

Primary Settling

Primary settling will remove about 25 to 35 percent of the BOD_5 and from 60 to 65 percent of the suspended solids of the raw domestic wastewater. Sludges removed in primary treatment are (1) solids removed by screening or changed by comminution equipment, (2) grit and similar solids, (3) skimming, usually pumpable, (4) settled sludge, usually 5 to 8 percent solids (the solids loading is increased if there is a substantial amount of ground garbage), and (5) waste sludge from secondary clarifiers (Ref. III-24).

Screenings are materials such as rags, sticks, and garbage in the raw wastewater that are removed on bar racks or screens placed at the head end of the treatment plant. The quantity of screenings captured in a wastewater treatment plant will vary depending upon the size of screen opening. Approximately 3.7×10^{-3} to 45×10^{-3} cubic meters of screenings per 1000 cubic meters ($m^3/k\text{-}m^3$) of sewage are removed in openings of 1.3 to 5.1 centimeters and 37.3×10^{-3} to 224.3×10^{-3} $m^3/k\text{-}m^3$ for openings of 0.2 to 1.9 cm [0.5 to 6.0 cubic feet of screenings per million gallons (ft^3/MG) are removed in openings of 1/2 to 2 inches and 5.0 to 30 ft^3/MG for openings of 3/32 to 3/4 inches] (Ref. III-25). Screenings have a moisture content of 85 to 95 percent and an organic content of 50 to 80 percent (Ref. III-25). Because of the high organic content, the screenings may either be incinerated in a separate unit, in a skimmings incinerator, in a refuse incinerator, or a dewatered sludge incinerator. They may also be ground by hammermill shredders and added to the sewage for later removal in sedimentation basins.

Heavy inert material or grit such as sand, silt, gravel, ashes, and coffee grounds are selectively deposited in units installed at the head of the wastewater treatment plant, either by velocity control in simple gravity settling chambers or classification of inert and lighter organic matters in dissolved air flotation tanks. However, if septic wastewaters are expected, aeration tanks should be covered to control odors. The quantity of grit collected varies from 7.4×10^{-3} to 87×10^{-3} $m^3/k\text{-}m^3$ with an average of 30×10^{-3} $m^3/k\text{-}m^3$ (1 to 12 ft^3/MG with an average of 4 ft^3/MG) with a moisture content of 14 to 34 percent (Ref. III-25). Grit is often washed after collection to reduce the organic concentration which may be as high as 50 percent of the total grit solids. The grit removed may be sent to a landfill and covered to guard against odors. "Well-washed grit has been used on sludge drying beds, as a cover for screenings, and as a surfacing material for walks and roadways. A few sewage treatment plants have incinerated grit along with dewatered sludge. Being largely inorganic, most of the grit solids are ultimately discharged with the incinerator ash" (Ref. III-25).

Skimmings, consisting of all types of floatable materials collected from sedimentation basins, normally vary in volume from 0.7×10^{-3} to 52.3×10^{-3} $m^3/k\text{-}m^3$ (0.1 to 7 ft^3/MG), a moisture content of 60 to 90 percent, and a volatile solids concentration of 90 to 95 percent (Ref. III-25). Because skimmings include high concentrations of grease and fibrous trash, the heat value is considerably higher than screenings or grit.

Skimmings are currently disposed in one of four ways: (1) buried, (2) pumped to digesters, (3) dewatered by mechanical equipment, or (4) incinerated. Burial of skimmings is simple, but they must be covered immediately to control nuisance problems. Disposal to digesters is common, particularly with completely mixed units. However, without thorough digester mixing the skimmings may create a scum layer within the digester which leads to operational problems. Vacuum filtration dewatering would normally require prior mixing with more readily drained materials or the use of a sludge precoat on the filter. Incineration of just the skimmings may be a problem due to development of high operating temperatures from the combustion of this highly volatile and high energy-value material. The most common technique is to incinerate the skimmings in the same furnace along with vacuum filter, pressure filter, or centrifuge cake solids.

Grease recovery and reuse is not practical from wastewater treatment plant skimmings because the volume of skimmings is small and the grease is too contaminated with other materials. Purifying the grease is presently too expensive and approval for domestic reuse by the Federal Drug Administration would be doubtful (Ref. III-25).

Secondary Treatment

Trickling Filters

Conventional trickling filters use rock media on which biological organisms are attached. As the wastewater effluent from the primary settling process flows down through the filter, the biological growths adsorb, absorb, and remove various pollutants. Biological activity results in cell synthesis which is a significant portion of the total sludge produced. A portion of the organics or other pollutant matter will be converted by biological synthesis into a solid. The excess solids not required for carrying on the treatment process slough off the rock surfaces and settle out in the final clarifier. The BOD_5 loading of the filter will determine to a large extent the physical and biological characteristics of the excess solids (Ref. III-24). Standard-rate filters will generate about 0.25 pounds of solids per pound of BOD_5 removed, while high-rate filters generate about 0.50 to 0.85 pounds per pound of BOD_5 removed (1 pound = 454 grams). In recent years plastic media, usually polyvinyl chloride, have been used as biological support surfaces for high BOD_5 loadings per unit volume. Solids production with these media increases to between 0.5 and 1.0 pound per pound of BOD_5 removed. The solids from trickling filters thicken in the final clarifier to 2 to 3 percent by weight, the denser solids resulting from low-loaded filters.

The rotating biological contactor is a type of fixed media filter similar in concept to a trickling filter (Ref. III-26). A series of plastic disks are mounted on a horizontal shaft and closely spaced providing a relatively large area for biological growths. Wastewater flows through a tank in a direction perpendicular to the slowly rotating disks which are submerged to about three-eighths of their diameter (Ref. III-24). "The alternate contacting of the disks with the wastewater and the atmosphere provides oxygen for biological removal of biodegradable pollutants from the wastewater. Removals of 85 to 90 percent BOD_5 and suspended solids from domestic wastewater have been reported. The solids slough off the disks and are carried with the flow to a final clarifier. The quantity and physical characteristics of the solids are comparable to those from trickling filters" (Ref. III-24).

Activated Sludge

Activated sludge processes use a suspension of aerobic microorganisms to remove soluble and collodial organic matter. These organisms can vary in type, concentration, and degree of agglomeration depending upon various physical features of the plant, types of pollutants, and degree of pollutant level. There are many modifications of the activated sludge process beyond the scope of this study to investigate; however, the major processes are discussed below.

High-rate aerobic activated sludge processes maintain organism suspensions in the range of 2000 to 5000 mg/l and are designed primarily for the removal of carbonaceous BOD_5. These processes are characterized by high rates of excess solids production between 0.5 and 0.8 pound per pound of BOD_5 removed. Low-rate processes, on the other hand, are designed to convert ammonia to nitrates. The types of organisms in this process have a low reproductive (cell synthesis) rate with correspondingly much lower excess solids produced per pound of ammonia (nitrogenous BOD_5) oxidized.

It should be noted that variations in the design parameter of the process can result in wide ranges in the character and amount of the excess solids produced. For example, in using oxygen rather than air, "the concentration of the sludge drawoff from the final clarifier in the oxygen system is about 1.0 to 2.5 percent; in the normal operation of an activated sludge system using air the solids are usually not more than about 1 to 1.5 percent by weight" (Ref. III-24). It has also been noted that the use of oxygen in the activated sludge process can reduce up to 40 percent by weight the amount of excess sludge to be disposed (Ref. III-27).

Chemical Addition to Primary Treatment

Chemical treatment of raw wastewater can reduce BOD_5 loads to an existing secondary plant and it can also precipitate and remove phosphorus from the wastewater. Alum, iron salts, lime, or organic polymers are used to flocculate and settle finely divided suspended solids and a portion of the colloids in a primary clarifier. Because of its low cost, lime treatment is frequently used. Depending upon the degree of phosphorus removal desired, lime is added to raise the pH of the wastewater to between 9.5 and 11.5. The settled sludge is quite dense (5 percent solids at pH >11.5 and 11 percent solids at pH <11.5) and is usually dewatered without further conditioning (Ref. III-24). Table III-5 indicates the additional sludge to be handled with chemicals in the primary treatment system. Sludges produced in alum or iron coagulation can be digested. "No solubilization of the precipitated aluminum phosphate occurs, though some may occur when ferric phosphate is reduced to the ferrous form in an anaerobic digester" (Ref. III-24). Care must be taken in anaerobically digesting high lime sludge to prevent digester upset (Ref. III-24). Lime treatment has the advantage in that lime can be recovered in a recalcination facility, thus reducing the amount of lime sludge for ultimate disposal as well as recovering a resource.

Tertiary Treatment

Chemical Addition to Secondary Treatment

The requirement for low phosphorus levels in treated wastewater effluents has seen the increased use of chemical addition to biological processes to provide tertiary treatment. Alum or iron salts or lime can be added to the activated sludge aeration basin, in a separate mixing basin just prior to the final clarifier, or in the secondary effluent with subsequent filtration or settling of the solids. The hydroxide produced coagulates the finer particles in the biological suspension and improves the clarification and settleability. Since the settled sludge is generally denser, the total volume of sludge is not greatly increased although the quantity of solids has increased. Tables III-6 and III-7 indicate the additional sludge expected from chemical additions to a biological secondary wastewater treatment facility.

A review of Tables III-5, III-6, and III-7 indicates that (1) lime addition to the primary system creates the greatest increase in sludge mass, and (2) the use of alum in the aeration basins creates the least increase in sludge mass. However, the decisions as to what type of chemical to use and its point of application, particularly in the upgrading of existing

TABLE III-5

ADDITIONAL SLUDGE TO BE HANDLED WITH CHEMICAL TREATMENT SYSTEMS

PRIMARY TREATMENT FOR REMOVAL OF PHOSPHORUS

Sludge Production Parameter		Con-ventional Primary	Low Lime Addition to Primary Influent	High Lime Addition to Primary Influent	Alum (Al^{+++}) Addition to Primary Influent	Iron (Fe^{+++}) Addition to Primary Influent
Level of chemical addition (mg/1)		0	350-500	800-1,600	13-22.7	25.8
Percent sludge solids	Mean	5.25	11.1	4.4	1.2	2.25
	Range	5.0-5.5	3.0-19.5	2.1-5.5	0.4-2.0	1.0-4.5
lb/MG	Mean	788	5,630	9,567	1,323	2,775
	Range	600-950	2,500-8,000	4,700-15,000	1,200-1,545	1,400-4,500
gal/MG	Mean	4,465	8,924	28,254	23,000	21,922
	Range	3,600-5,000	4,663-18,000	16,787-38,000	10,000-36,000	9,000-38,000

Note: lb/MG = pounds per million gallons

gal/MG = gallons per million gallons

Source: Ref. III-28

TABLE III-6

ADDITIONAL SLUDGE TO BE HANDLED WITH CHEMICAL TREATMENT SYSTEMS

PHOSPHORUS REMOVAL BY MINERAL ADDITION TO AERATOR

Sludge Production Parameter		Al^{+++} Addition to Aerator		Fe^{+++} Addition to Aerator	
		Conventional Secondary	With Al^{+++} Addition	Conventional Secondary	With Fe^{+++} Addition
Level of chemical addition (mg/l)		0	9.4-23	0	10-30
Percent sludge solids	Mean	0.91	1.12	1.2	1.3
	Range	0.58-1.4	0.75-2.0	1.0-1.4	1.0-2.2
lb/MG	Mean	672	1,180	1,059	1,705
	Range	384-820	744-1,462	918-1,200	1,100-2,035
gal/MG	Mean	9,100*	13,477	10,650*	18,650
	Range	7,250-12,300	7,260-20,000	10,300-11,000	6,000-24,000

*Difference due to the fact that different plants were evaluated.

Source: Ref. III-28

facilities, will be made considering not only the additional sludge mass produced but also the sludge processing equipment available and the ease of sludge handling and treatment.

Physical-Chemical Treatment

Physical-chemical treatment can be either a secondary or tertiary treatment process depending upon the types and amounts of chemicals added and the unit process employed. The type of treatment is non-biological using lime, alum, or iron salts to coagulate phosphorus, heavy metals, and suspended solids in raw or partially treated wastewaters. Lime has been particularly effective in that it produces a dense sludge that thickens and dewaters easily, it can be reclaimed by recalcination for reuse, and it is relatively inexpensive. Following chemical coagulation, the wastewater may go to dual-media (such as coal-sand) filters for suspended solids removal followed by activated carbon columns for residual high molecular weight organic removal. Suggested advantages of physical-chemical treatment versus biological treatment are given in Table III-8.

TABLE III-7

ADDITIONAL SLUDGE TO BE HANDLED WITH CHEMICAL TREATMENT SYSTEMS

PHOSPHORUS REMOVAL BY MINERAL ADDITION TO SECONDARY EFFLUENT

Sludge Production Parameters		Lime Addition	Alum (Al^{+++}) Addition	Iron (Fe^{+++}) Addition
Level of chemical addition (mg/l)		268-450	16	10-30
Percent sludge solids	Mean	1.1	2.0	0.29
	Range	0.6-1.72	--*	--*
lb/MG	Mean	4,650	2,000	507
	Range	3,100-6,800	--*	175-781
gal/MG	Mean	53,400	12,000	22,066
	Range	50,000-63,000	--*	6,000-36,000

* Not measured

Source: Ref. III-28

TABLE III-8

ADVANTAGES OF PHYSICAL-CHEMICAL TREATMENT

VERSUS CONVENTIONAL BIOLOGICAL TREATMENT

(1) Less Land Area Requirement (1/2 to 1/4) Than Biological Systems
(2) Less Sensitivity to Diurnal Variations (Greater Stability)
(3) Not Affected by Toxic Metals
(4) Potential for Significant Heavy Metal Removal
(5) Superior Removal of Phosphorus Compounds
(6) Greater Flexibility in Design and Operation
(7) Modular Design Capability
(8) Capability to Accommodate Increased Flows

Source: Ref. III-29

Disadvantages of physical-chemical treatment include an inability to remove low-molecular-weight organics (sugars, alcohols, etc.) and higher operating costs due to increased chemical usage. This requirement for increased quantities of chemicals consequently results in an increase in the total mass of solids to be handled and disposed. Since the solids generated are denser, the volume of sludges to be handled, however, may not be any greater than experienced in biological treatment systems. Table III-9 indicates for specific chemical dosages the anticipated sludge production.

TABLE III-9

SLUDGE PRODUCTION CHARACTERISTICS FOR PHYSICAL-CHEMICAL TREATMENT OF WASTEWATERS

Process Parameter	Ferric Chloride (Fe^{+++})	Alum (Al^{+++})	Hydrated Lime
Chemical Dosage (mg/l)	120	150	460
Sludge Production			
Wastewater (lb/MG)	700	700	700
Chemical (lb/MG)	700	500	6300
Total (lb/MG)	1400	1200	7000
Blowdown Solids (gm/l)	13	3	120

Source: Ref. III-29

SUMMARY

As new wastewater treatment facilities are designed or existing facilities are upgraded to meet current and projected discharge requirements of the Act, proper consideration as to the expected quantities and qualities of sludge must be given. The previous sections of this chapter are intended to serve as guidance to the 208 planning agency in the development of general quantities and qualities of sludges generated for various types of wastewater treatment technologies.

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CHAPTER IV

SLUDGE HANDLING AND TREATMENT

INTRODUCTION

Previous work has characterized the processes used and their functions in the treatment of sludges as shown in Table IV-1. The following sections of this chapter are devoted to a brief description of techniques and equipment available to carry out the process functions.

THICKENING

Thickening of waste sludges removed from primary and secondary clarifiers is desirable for several reasons, notably:

(1) the reduced volume of thickened sludge decreases the costs of conveyance and ultimate disposal;

(2) fluctuations in sludge quality and quantity passing to subsequent processes is lessened and less chemical conditioning is necessary prior to further dewatering; and

(3) digester operation is improved because a higher solids loading is attainable, bacterial digestion becomes more efficient, heating requirements (in anaerobic digestion) are reduced, and less volume of supernatant liquor is produced (Ref. IV-2).

The most common methods for thickening are mechanical gravity thickening, air flotation, and centrifugation. The occurrence of these thickening methods and the type of sludge for which they are generally applicable are shown in Table IV-2.

Gravity Thickening

The most conventional approach to sludge thickening of either primary, excess activated, or trickling filter sludges has been by the use of mechanical gravity thickeners.

The concentrations expected from mechanical gravity thickeners for various types and combinations of sludges are given in Table IV-3. The quality of the thickener overflow is determined by the type and characteristics of the sludge being thickened. "The overflow liquid from gravity thickening of municipal primary and biological sludges has a suspended solids content of about 150 to 300 mg/l and a BOD_5 of about 200 mg/l" (Ref. IV-4). Table IV-3 indicates that better overall operation of a gravity thickener can be obtained when mixed sludges are thickened rather than when each type of sludge is thickened independently.

TABLE IV-1

SLUDGE TREATMENT PROCESSES AND THEIR FUNCTIONS

Unit Processes	Functions
Thickening (Blending)	- Water Removal - Volume Reduction - Post Process Efficiencies - Blending
Stabilization (Reduction)	- Pathogen Destruction - Volume and Weight Reduction - Odor Control - Putrescibility Control - Gas Production
Conditioning (Stabilization)	- Improve Dewatering or Thickening Rate - Improve Solids Capture - Improve Compactability - Stabilization
Dewatering	- Water Removal - Volume and Weight Reduction - Change to Damp Cake - Reduces Fuel Requirements for Incineration/ Drying
Heat Drying and Reduction (Stabilization)	- Destruction of Solids - Conversion

Source: Ref. IV-1

Centrifugation

Centrifuges may be used for thickening waste activated sludge or primary sludges. However, because centrifugation of primary sludges can concentrate the solids to approximately 25 percent, this process is usually considered a dewatering step for primary sludges. The sludge cake of approximately 75 to 80 percent moisture contains a solids concentration of from 15 to 30 percent.

TABLE IV -2

OCCURRENCE OF THICKENING METHODS IN SLUDGE TREATMENT

Method	Type Sludge	Other Pertinent Considerations	Frequency of Usage and Relative Success
Gravity	Raw Primary	Separate Air EAS Thickening	Increasing-excellent results
Gravity	Digested Primary	Separate EAS Thickening	Infrequent now; but feasible
Gravity	Raw Primary and EAS	Recirculation of Air EAS to Primaries	Decreasing-usually poor
Gravity	Raw Primary and EAS	Direct Mixed Sludge Thickening	Some new installations-marginal results
Gravity	Air EAS	Separate Primary Sludge Thickening	Essentially never used-poor results
Gravity (Elutriation)	Digested Primary and EAS Mixture	Secondary Digesters or Elutriation	Many plants built-requires flocculants
Dissolved Air Flotation	Raw Primary and EAS	Direct Mixed Sludge Thickening	Rarely used
Dissolved Air Flotation	Air EAS	Separate Gravity Thickening of Primary	Increasing-good results
Solid Bowl Conveyor Type Centrifuge	Air EAS	Separate Gravity Thickening of Primary	Some limited use-solid capture problem
Disc Type Centrifuge	Air EAS	Separate Gravity Thickening of Primary	Some limited use-data now being accumulated

Note: EAS = Excess Activated Sludge
Air EAS = Excess Activated Sludge using Air rather than Oxygen

Source: Ref. IV-1

TABLE IV-3

CONCENTRATIONS OF UNTHICKENED AND THICKENED SLUDGES AND SOLIDS LOADINGS FOR MECHANICAL THICKENERS

Type of Sludge	Sludge, percent solids		Solids loading for mechanical thickeners, lb/sq ft/day
	Unthickened	Thickened	
Separate sludges:			
Primary	2.5-5.5	8-10	20-30
Trickling filter	4-7	7-9	8-10
Modified aeration	2-4	4.3-7.9	7-18
Activated	0.5-1.2	2.5-3.3	4-8
Combined sludges:			
Primary and trickling filter	3-6	7-9	12-20
Primary and modified aeration	3-4	8.3-11.6	12-20
Primary and activated	2.6-4.8	4.6-9	8-16

Note: lb/sq ft/day x 4.89 = kg/sqm/day, where kg = 1000 grams and sqm = square meters

Source: Ref. IV-3

The centrate is relatively high in suspended, non-settling solids, which, if discharged back to the waste treatment plant, would adversely affect the removal of suspended solids for the final effluent. This problem may be alleviated by the addition of a sludge coagulating/conditioning agent such as lime, ferric chloride, or organic polymers, albeit at an increased cost (Ref. IV-5).

Centrifuges have substantial disadvantages such as high power costs, complex maintenance, and the need for conditioning chemicals to provide optimum solids retention (Ref. IV-2).

Horizontal scroll centrifuges can produce a 21 percent solids sludge cake with unconditioned digested sludge and 25 percent solids cake from

TABLE IV-4

CENTRIFUGAL THICKENING PERFORMANCE DATA

Type of Sludge	Centrifuge Type	Capacity (gpm)	Feed Solids (%)	Under-flow Solids (%)	Solids Recovery (%)	Polymer Requirement (lb/ton)
EAS	Disc	150	0.75-1.0	5-5.5	90+	None
EAS	Disc	400	-	4.0	80	None
EAS (after Roughing Filter)	Disc	50-80	0.7	5-7	93-87	None
EAS (after Roughing Filter)	Disc	60-270	0.7	6.1	97-80	None
EAS	Basket	33-70	0.7	9-10	90-70	None
EAS	Solid-Bowl	10-12	1.5	9-13	90	-
EAS	Solid-Bowl	75-100	0.44-0.78	5-7	90-80	None
EAS	Solid-Bowl	110-160	0.5-0.7	5-8	65 85 90 95	None <5 5-10 10-15

Note: EAS = Excess Activated Sludge
gpm = gallons per minute

Source: Ref. IV-1

digested, heat conditioned, and thickened sludge with polymer conditioning chemicals (Ref. IV-6).

The thickening performance of disc, basket, and solid bowl centrifuges is given in Table IV-4.

Dissolved Air Flotation

Flotation thickeners are used primarily with waste activated sludge and will generally produce a sludge with about four percent solids. Higher float concentrations, averaging six percent and ranging as high as eight percent, have been obtained with mixtures of primary and waste activated sludges (Ref. IV-3). The use of polyelectrolytes can increase the solids collected in a flotation thickener. However, these polyelectrolytes are expensive and can add considerably to the overall cost of the thickening process.

Table IV-5 indicates the performance data for flotation thickening. Flotation thickeners are more expensive and difficult to operate than gravity thickeners. However, due to reduced retention times and subsequently smaller tank volumes, they do offer the advantage of lower capital costs (Ref. IV-2). Flotation thickening is also more reliable in thickening light sludges which rise quickly and compact readily in flotation tanks but which would become putrified in gravity thickeners before achieving the desired concentration.

STABILIZATION

There are several methods available for stabilizing a conditioned and thickened sludge. This section is devoted to a general discussion of these treatment methods. Each method has its own advantages and disadvantages and would be considered for use depending upon both the nature of the sludge entering the treatment process, the mode of further treatment, and the final disposal planned for the resultant treated sludge and by-products.

Anaerobic Digestion

Anaerobic digestion can be defined as the decomposition of organic matter in the absence of free oxygen. The decomposition is accompanied by gasification, liquefaction, stabilization, colloidal structure breakdown, and release of moisture (Ref. IV-5). Generally, the digestion process is not complete and intermediate products such as organic acids, ammonia, methane, hydrogen sulfide, carbon dioxide, and carbonates are produced (Ref. IV-5). Depending upon the initial volatile solids content of the sludge to be treated, anaerobic digestion can achieve a 60 to 70 percent reduction in volatile solids. The purposes of anaerobic treatment (Ref. IV-5) are generally to:

(1) prevent nuisance by decomposing organic solids to a more stable form;

(2) reduce sludge volume by converting organic solids to gases and liquids;

(3) reduce volume by concentrating the remaining solids into a dense sludge;

(4) store sludge to accommodate fluctuations in wastewater flows and to permit flexibility in subsequent dewatering operations;

(5) homogenize sludge solids to facilitate subsequent handling procedures;

(6) produce a more easily dewatered sludge; and

(7) reduce pathogenic organisms.

TABLE IV-5

PERFORMANCE DATA FROM FLOTATION THICKENING

Sludge Type	Chemical Flotation Aids Required	Loading (lb/sq ft/day)	Sludge Concentration		
			Feed (%)	Thickened (%)	Recovery (%)
Waste activated	No	10.0	0.5-1.0	4.1	90.0
Waste activated	No	11.3	0.6-1.5	4.0	87.0
Waste activated	No	11.7	0.8	4.6	84.6
Waste activated	No	11.8	0.5	5.5	85.0
Waste activated	No	12.3	0.6	6.5	93.0
Waste activated	No	18.5	0.4	4.0	88.3
Waste activated	No	20.0	0.7	4.5	99+
Waste activated	No	25.3	1.0	4.6	83.4
Waste activated	Yes	14.0	0.5	3.0	85.0
Waste activated	Yes	20.0	0.7	3.0	85.0
Waste activated	Yes	48.0	0.5	4.0	95.0
Mixture*	No	18.2	---	7.3	---
Mixture*	No	22.8	0.5	8.6	91.0
Mixture*	No	23.5	1.2	6.0	85.0
Mixture*	No	32.8	1.6	7.3	87.0
Mixture*	No	18.6 (Primary) +22.8 (EAS)	---	5.3	---
Mixture*	No	29.4 (Primary) +17.3 (EAS)	---	7.0	94.4

*Mixture = Waste activated + primary

Note: lb/sq ft/day x 4.89 = kg/sqm/day

As high as possible a sludge solids feed concentration to the digester is desirable (Ref. IV-5) because:

(1) it conserves heat due to the minimum amount of water present;

(2) it encourages microorganism efficiency because their food supply is concentrated;

(3) it increases detention times;

(4) it minimizes supernatant volume returned to other treatment processes; and

(5) it promotes the efficiency of subsequent dewatering steps.

High-rate digestion, by increasing the loading rates and thus decreasing the detention times, has been employed primarily to reduce costs associated with tankage. However, high-rate digested sludge resists compaction and effective liquids separation. Consequently, the supernatant liquid has a high solids content. Table IV-6 compares the properties of digester supernatant from standard and high-rate digestion. Table IV-7 gives an indication of digestion tank capacity requirements to be expected for the anaerobic digestion of various biological treatment processes. The return of supernatant to the head of the wastewater treatment process results in an additional load on the system which causes treatment problems. Unless the wastewater treatment plant is properly designed to handle this additional load, the supernatant must be treated in a separate system, usually an aerobic biological plant.

Digester gas given off in the process of anaerobic digestion may be used to mix the contents of the tank or as a fuel for boilers and internal combustion engines used for pumping sewage, operating blowers, and electricity generation. Gas production estimated on a per capita basis is about 0.3 to 0.6 cubic feet (8.5×10^{-3} to 17×10^{-3} cubic meters) in an unheated digester and from 0.6 to 0.8 cubic feet (17×10^{-3} to 22×10^{-3} cubic meters) in heated digesters (Ref. IV-1). The digester gas has a heat value of approximately 600 BTU/ft^3 (5350 kilogram-calories/cubic meter) (Ref. IV-5). If the hydrogen sulfide content of the gas is high, the gas must be scrubbed before discharge to the atmosphere. The scrubber water could be discharged back to the wastewater treatment plant. Table IV-8 indicates the characteristics of digested sludge gas. Recovery of the methane off-gas and reuse for in-plant electrical generation to power motors, pumps, and blowers is feasible. "Should electric generation be considered, approximately 3.5 cubic feet of gas is required to produce 1 kilowatt hour (kwh) of electricity" (Ref. IV-1). Tables IV-9 and IV-10 indicate the qualities of anaerobically digested sludge.

TABLE IV-6

PROPERTIES OF DIGESTER SUPERNATANT FROM ANAEROBIC DIGESTION

Item	Standard Rate	High Rate
Temperature, Fahrenheit	85-90	110-125
Total suspended solids (mg/1)	4000-5000	10,000-14,000
Total solids (mg/1)	2000-3000	4000-6000
BOD_5 (mg/1)	2000-3000	6000-9000
Volatile solids (mg/1)	650-3000	2400-3800
Alkalinity (mg/1)	1000-2400	1900-2700
Color (units)	3000-4000	4900-6700
H_2S (mg/1)	70-90	190-440
NH_3-Nitrogen (mg/1)	240-560	560-620
pH (units)	7.0-7.6	6.4-7.2
Odor	Slightly Offensive	Offensive
Digester loading	0.15 lb BOD_5/cu ft/day	0.4 lb BOD_5/cu ft/day

Source: Ref. IV-4

Aerobic Digestion

Aerobic digestion taking place in the presence of free oxygen is a process by which microorganisms oxidize their cell protoplasm and the biologically degradable organic matter in the sludge to carbon dioxide, water, and ammonia. The ammonia is then converted to nitrates as the aerobic digestion proceeds. A final material is produced consisting of inorganics and volatile solids that resist further biological degradation. Aerobic digestion tanks are not normally covered or heated and are similar to conventional aeration tanks.

The advantages claimed for aerobic versus anaerobic digestion (Ref. IV-3) are:

(1) volatile solids reductions similar to that obtained anaerobically;

(2) lower BOD_5 concentrations in the supernatant liquor, generally around 100 mg/1;

TABLE IV-7

ANAEROBIC DIGESTION-TANK CAPACITY REQUIREMENTS*

Type of Plant	Wet Sludge			Volume Required	
	Dry solids, lb/capita/day	Percent solids	cu ft/capita/day	34-45 days detention, cu ft/capita	Ten States Standards, cu ft/capita
Primary	0.12	5	0.038	1.3-1.7	2-3
Primary + trickling filter	0.18	4	0.072	2.5-3.2	4-5
Primary + activated sludge	0.19	3	0.100	3.5-4.5	4-6

* Based on 0.20 lb of suspended solids per capita per day in raw sewage.

Note: 1 pound = 454 grams
1 cu ft (cubic foot) = 0.0283 cu m (cubic meter)

Source: Ref. IV-3

(3) production of an odorless, humus-like, biologically stable end product with excellent dewatering characteristics;

(4) recovery of more of the basic fertilizer value of the sludge;

(5) fewer operational problems; and

(6) lower capital costs.

The major disadvantages are higher power costs associated by supplying the required oxygen and loss of a useful by-product such as methane (Ref. IV-8).

The use of pure oxygen in a closed-tank system for aerobic digestion has been investigated (Ref. IV-9). It was noted that much of the heat generated in the digestion process was retained by the system, resulting in a significant increase in the sludge temperature and consequently an increase in the rate of sludge destruction.

Table IV-11 indicates the characteristics of aerobic digestion supernatants from seven such facilities. The ranges in values are due to the type of solids-liquid separation processes, digester loading rates, and

TABLE IV-8

CHARACTERISTICS OF SLUDGE GAS FROM ANAEROBIC DIGESTION

Constituent	Values for Various Plants Percent by Volume							
CH_4	42.5	61.0	62.0	67.0	70.0	73.7	75.0	73-75
CO_2	47.7	32.8	38.0	30.0	30.0	17.7	22.0	21-24
H_2	1.7	3.3	trace	*	*	2.1	0.2	1-2
N_2	8.1	2.9	trace	3.0	*	6.5	2.7	1-2
H_2S	*	*	0.15	*	0.01-0.02	0.06	0.1	1-1.5
H_0 (BTU/ft^3)	459	667	660	624	728	791	716	739-750
d_v (air)	1.04	0.87	0.92	0.86	0.85	0.74	0.78	0.70-0.80

* Negligible

Note: d_v = volumetric density, compared to air

Source: Ref. IV-1

nature of the sludges. Although the aerobic digestion process is relatively new in terms of its use, a general volume allowance of three to four cubic feet (8.5×10^{-2} to 11×10^{-2} cubic meters) per capita has been established as a reasonable design parameter (Ref. IV-1).

Chemical Treatment

Lime has been added to settled sludge in quantities sufficient to raise the pH to between 11 and 11.5. The lime stabilized sludge dewaters well on sandbeds without odor problems. The effect of lime addition on the filterability using vacuum filters has been investigated (Ref. IV-10). The wastewater treatment plant at Lebanon, Ohio, was being upgraded for phosphorus removal by the addition of alum or iron salts. Lime added to the resulting sludges stabilized the sludge, produced no obnoxious odors, and increased the filterability of the sludge by a factor of about two, while cake moisture remained unchanged.

TABLE IV-9

TYPICAL CHEMICAL COMPOSITION OF RAW AND ANAEROBICALLY DIGESTED SLUDGE

Item	Raw Primary Sludge		Digested Sludge	
	Range	Typical	Range	Typical
Total dry solids (TS), %	2.0-7.0	4.0	6.0-12.0	10.0
Volatile solids (% of TS)	60-80	65	30-60	40.0
Grease and fats (ether soluble, % of TS)	6.0-30.0	---	5.0-20.0	---
Protein (% of TS)	20-30	25	15-20	18
Nitrogen (N, % of TS)	1.5-4.0	2.5	1.6-6.0	3.0
Phosphorus (P_2O_5, % of TS)	0.8-2.8	1.6	1.5-4.0	2.5
Potash (K_2O, % of TS)	0-1.0	0.4	0.0-3.0	1.0
Cellulose (% of TS)	8.0-15.0	10.0	8.0-15.0	10.0
Iron (not as sulfide)	2.0-4.0	2.5	3.0-8.0	4.0
Silica (SiO_2, % of TS)	15.0-20.0	---	10.0-20.0	---
pH	5.0-8.0	6.0	6.5-7.5	7.0
Alkalinity (mg/liter as $CaCO_3$)	500-1,500	600	2,500-3,500	3,000
Organic acids (mg/liter as HAc)	200-2,000	500	100-600	200
Thermal content (BTU/lb) (kg cal/g)	6,800-10,000 3.7-5.6	7,600* 4.2*	2,700-6,800 1.5-3.7	4,000** 2.2**

Note: --- means data not shown in reference cited.

* Based on 65 percent volatile matter.
** Based on 40 percent volatile matter.

Source: Ref. IV-3

TABLE IV-10

CHEMICAL COMPOSITION OF VARIOUS SEWAGE SLUDGES

Location	Type of Sludge	Total Nitrogen (%)	Carbon (%)	Carbon/ Nitrogen Ratio (%)	Phos- phoric Oxide (%)	Acid Soluble Potassium (%)	Ash (%)
Washington, D. C.	Influent solids	2.39	43.69	18.3	1.09	---	37.59
	Digested sludge	2.06	28.59	13.9	1.44	0.14	52.83
Baltimore, Md.	Influent solids	2.23	47.09	21.1	1.29	---	24.16
	Activated sludge	2.36	30.37	12.4	11.01	---	29.70
	Heat dried digested sludge	3.05	36.53	12.0	2.97	---	39.73
Jasper, Ind.	Influent solids	2.90	42.31	14.6	1.62	---	32.29
	Activated sludge	3.51	23.01	6.6	2.81	---	52.43
	Digested sludge	5.89	22.95	3.9	3.49	---	36.96
Richmond, Ind.	Influent solids	3.80	28.21	7.4	5.19	---	40.94
	Activated sludge	3.02	44.04	14.6	3.64	---	31.37
	Digested sludge	2.24	26.36	11.8	4.34	---	50.09
Chicago, Ill.*	Raw sludge	2.70	46.62	17.3	2.71	---	28.24
	Activated sludge	4.98	28.62	5.7	5.58	---	34.82
	Heat dried sludge	5.56	29.41	5.3	6.56	---	37.42
Milwaukee, Wis.*	Activated sludge	5.96	---	---	3.96	0.41	27.70
Rochester, N. Y.	Digested sludge	2.54	---	---	1.16	0.24	42.80
Des Moines, Ia.	Digested primary and activated sludge	1.81	---	---	3.31	0.40	61.40

* Undigested

Note: --- means data not taken.

Source: Ref. IV-7

TABLE IV-11

CHARACTERISTICS OF AEROBIC DIGESTION SUPERNATANT FROM SEVEN FACILITIES

Parameter	Average	Range
pH	7.0	5.9-7.7
	--------------mg/l----------------	
BOD_5	500	9-1,700
Filtered BOD_5	51	4-183
COD	2,600	288-8,140
Suspended Solids	3,400	46-11,500
Kjeldahl N	170	10-400
Total Phosphorus	98	19-241
Soluble Phosphorus	26	2.5-64.0

Source: Ref. IV-1

CONDITIONING

Sludge conditioning improves the dewaterability of the sludges by changing its chemical and physical characteristics.

Chemical Addition

The use of chemicals for sludge conditioning is widely used method to employ because of the increased yields and greater flexibility obtained for subsequent sludge treatment and disposal processes. Chemicals such as ferric chloride, lime, alum, chlorine, and organic polymers are used for coagulation of the sludge solids and release of bound water. Intimate mixing of the sludge and coagulant is required for proper conditioning, and the detention times are generally short before the conditioned sludge is further processed. Flyash from electric power plants or from the incineration of sludges or solid wastes serves as an excellent sludge conditioner with the filter press for sludge dewatering. When flyash is not available, diatomaceous earth may also serve as a sludge conditioner. Table IV-12 is a listing of chemical dosages for various types of sludges. The specific resistance is indicative of the dewatering capabilities of sludges; the

TABLE IV-12

DOSAGE OF CHEMICALS FOR VARIOUS TYPES OF SLUDGES

(Conditioners in Percentage of Dry Sludge)

Description	Fresh Solids		Digested		Elutriated Digested	
	$FeCl_3$	CaO	$FeCl_3$	CaO	$FeCl_3$	CaO
Primary	1-2	6-8	1.5-3.5	6-10	2-4	---
Primary and trickling filter	2-3	6-8	1.5-3.5	6-10	2-4	---
Primary and activated	1.5-2.5	7-9	1.5-4	6-12	2-4	---
Activated (alone)	4-6	---	---	---	---	---

Note: --- means data not shown in reference cited.

Source: Ref. IV-3

lower the specific resistance, the easier the sludge is to dewater. The effect of anaerobic digestion as well as various chemical conditioners on reducing the specific resistance of sludges is shown in Table IV-13.

Elutriation

Elutriation, which involves mixing of digested sludge with water and resettling, does not improve the dewatering characteristics of the sludge. It does, however, reduce the chemical conditioner requirements. The elutriation process reduces the alkalinity of the sludge, thereby reducing the amount of ferric chloride required. Carried out in single-stage, multistage (series), or two-stage countercurrent operations, the elutriation process may use either treatment plant process water or a supplemental water source of low alkalinity. The elutriation process produces a liquid supernatant of high suspended solids and BOD_5 content which must either be treated separately or discharged to the head end of the wastewater treatment plant. Fortunately, the advent of polyelectrolytes has eliminated the need for elutriation because the flocculating tendencies are not adversely affected by alkaline sludges (Ref. IV-7).

TABLE IV-13

SPECIFIC RESISTANCE OF SLUDGES

Description		Specific Resistance (sec^2/gram) x 10^7 (general values)
Domestic activated sludge		2,800
Activated (digested)		800
Primary (raw)		1,310-2,110
Primary (digested)		380-2,170
Primary (digested)		1,350
Primary (digested)		
Detention Time	Stage	
7.5 days	1	1,590
10.0 days	1	1,540
15.0 days	1	1,230
20.0 days	1	530
30.0 days	1	760
15.0 days	2	400
20.0 days	2	400
30.0 days	2	480
Activated sludge + 13.5% $FeCl_3$		45
Activated sludge + 10.0% $FeCl_3$		75
Activated sludge + 125% (by weight) newsprint		15
Activated digested sludge + 6% $FeCl_3$ + 10% CaO		5
Activated digested sludge + 125% newsprint + 5% CaO		4.5

Note: All values were recorded at 500 g/sq cm (grams per square centimeter)

Source: Ref. IV-7

Heat Treatment

Heat treatment is a conditioning process involving heating the sludge for short periods of time under pressure. This heat treatment results in coagulation of the sludge solids, breakdown of the gel structure of the sludge, and reduction of the water affinity of the sludge solids. Thus, the sludge is sterilized, practically deodorized, and readily dewatered without the addition of conditioning chemicals. The thickened sludge can be filtered to a solids content of 40 to 50 percent. The supernatant waste liquor contains high concentrations of short-chain, water-soluble organics that must be treated either in a separate biological treatment or returned to the head of the wastewater treatment plant. "It is estimated that direct recirculation of the undiluted liquors to the treatment plant will result in a ten percent increase in effluent BOD_5 and a twenty percent increase in effluent COD. Such increases are normally undetectable by usual sampling and analytical methods used in sewage treatment plant control. It is recommended that, in situations where effluent COD concentration is a critical water quality criterion, separate biotreatment of the sludge liquors be employed" (Ref. IV-11). The off-gases produced in this heat treatment process could be conveyed to either the sludge incinerator or a separate catalytic combustion unit.

DEWATERING

There are several methods available for dewatering of sludges, namely the vacuum filter, the centrifuge, the filter press, lagoons, and sand drying beds. Sludge dewatering processes achieve a degree of moisture removal intermediate between those of thickening and drying. Dewatered sludge solids concentrations of 20 to 30 percent are common with organic solids, and values of 60 percent or more can be achieved with some inorganic sludges (Ref. IV-12). Table IV-14 indicates the relationship of dewatering to other sludge treatment processes.

Vacuum Filtration

Vacuum filtration is the most commonly used mechanical dewatering method in the United States. The solids capture using chemical conditioning can be very good and a relatively dry filter cake is produced (see Table IV-15). The filtrate from a vacuum filter can have suspended solids concentrations varying from 100 to 20,000 mg/l depending upon the sludge type, the degree and type of conditioning, the type of filter media, and the vacuum applied (Ref. IV-4). Discharge of this filtrate back to the main plant may reduce the plant's overall efficiency, thus necessitating the use of conditioning chemicals to increase the solids capture. Using these chemicals makes the vacuum filter a relatively expensive process, and there have also been problems with blinding of the filter media. "Durable stainless steel fabrics and self-cleaning features are improvements that offset to some degree the high costs of equipment, labor, and chemical conditioners" (Ref. IV-2). Table IV-15 indicates that it is more advantageous not to digest mixed sludges prior to vacuum filtration since the chemical requirements are higher.

Large vacuum filters are avilable which can continuously dewater up to 100 tons of dry solids per 24 hours with properly conditioned sludges. However, due to required periodic maintenance, design capacity generally is kept to 25 to 50 percent of maximum.

TABLE IV-14

THE RELATIONSHIP OF DEWATERING TO OTHER SLUDGE TREATMENT PROCESSES FOR TYPICAL MUNICIPAL SLUDGES

Method	Pretreatment Normally Provided		Normal Use of Dewatered Cake			
	Thickening	Conditioning	Landfill	Land Spread	Heat Drying	Incineration
Rotary Vacuum Filter	Yes	Yes	Yes	Yes	Yes	Yes
Centrifuge (Solid Bowl)	Yes	Yes	Yes	Yes	Yes	Yes
Centrifuge (Basket)	Variable	Variable	No	Yes	No	No
Drying Beds	Variable	Not Usually	Yes	Yes	No	No
Lagoons	No	No	Yes	Yes	No	No
Filter Presses	Yes	Yes	Yes	Variable	Not Usually	Yes
Horizontal Belt Filters	Yes	Yes	Yes	Yes	Yes	Yes

Source: Ref. IV-1

TABLE IV-15

TYPICAL ROTARY VACUUM FILTER RESULTS FOR SLUDGE CONDITIONED WITH INORGANIC CHEMICALS

Type Sludge	Chemical Dose (lb/ton)		Yield (lb/hr/ft^2)	Cake Solids (%)
	Ferric Chloride	Lime		
Raw Primary	1-2	6-8	6-8	25-38
Anaerobically Digested Primary	1-3	6-10	5-8	25-32
Primary + Humus	1-2	6-8	4-6	20-30
Primary + Air Activated	2-4	7-10	4-5	16-25
Primary + Oxygen Activated	2-3	6-8	5-6	20-28
Digested Primary and Air Activated	4-6	6-19	4-5	14-22

Note: lb/hr/ft^2 x 4.89 = kg/hr/m^2

Source: Ref. IV-1

Centrifugation

Centrifuges have also been used as a dewatering method as well as a thickening method. It can produce dewatered cakes generally comparable to those obtained by vacuum filtration (see Table IV-16). Centrifugation has several advantages over vacuum filtration; namely, it is simple, compact, totally enclosed (thereby reducing odor problems in the solids handling facilities), and normally used without chemical aids (Ref. IV-5). As with the vacuum filter, the centrate may have a high suspended solids content, which, if recycled back to the main treatment plant, may reduce the overall plant efficiency. If this were the case, conditioning chemicals may be required.

Basket centrifuges have been used principally in dewatering sludges in small wastewater treatment plants. The unit is a batch device with alternate charging of feed sludge and discharging of dewatered sludge cake.

TABLE IV-16

RESULTS OF CENTRIFUGATION OF SLUDGES

USING A SCROLL-TYPE CENTRIFUGE

Type of Sludge	Cake concentration (% solids)	Solids recovery (%)	
		without chemicals	with chemicals
Raw primary	28-35	85-90	>95
Digested primary	25-35	80-90	>95
Activated	6-10[a]	---	---
Raw primary and activated	18-24	50-80	>95
Digested raw and activated	18-24	50-70	>95

[a] Without chemicals

Source: Ref. IV-12

Sand Drying Beds

Sand drying beds are used to dewater digested sludge. Using drying beds for dewatering raw sewage is not practiced because raw sludge is odorous, it attracts insects, it does not dry satisfactorily when applied at reasonable depths, and the oil and grease discharged with the slimy raw sludge clog the sand bed pores and thereby seriously retard drainage (Ref. IV-5). Covered beds using greenhouse-type enclosures are used where it is necessary to dewater continuously throughout the year regardless of weather. These enclosures protect the drying sludge from rain, control odor and insects, and reduce the area required for drying by approximately 70 percent (Ref. IV-1).

The sludge dewaters by drainage through the sludge mass and supporting sand and by evaporation from the surface exposed to the air. Most of the water does leave by drainage; therefore, an adequate underdrain system is essential. The water collected in the underdrain system is generally discharged back to the head end of the treatment plant. The dried sludge moisture content is approximately 60 percent after 10 to 15 days under faborable conditions.

Table IV-17 indicates the criteria for the design of sandbeds, while Table IV-18 indicates the quality of the digested cake.

TABLE IV-17

CRITERIA FOR THE DESIGN OF SANDBEDS

Type of Digested Sludge	Area (sq ft/capita)	Sludge Loading Dry Solids (lb/sq ft/yr)
Primary	1.0	27.5
Primary and standard trickling filter	1.6	22.0
Primary and activated	3.0	15.0
Chemically precipitated	2.0	22.0

Note: sq ft x 0.0929 = sq m
lb/sq ft/yr x 4.89 = kg/sq m/yr

Source: Ref. IV-1

Lagoons

Lagoons for sludge dewatering have been commonly used in the United States, primarily because of land availability, ease of operation, and low cost. Sludge is periodically removed and the lagoon is refilled. Prior to filling, the sludge must be stabilized to prevent odor problems.

Recommendations for required area vary from one square foot per capita (9.3×10^{-2} square meters) for primary digested sludge in arid climates to three to four square feet (28×10^{-2} to 37×10^{-2} square meters) per capita for activated sludge plants in areas where the annual rainfall is 36 inches (Ref. IV-1). Other design considerations include groundwater protection, climate, subsoil permeability, and lagoon depth. Sludge may be dewatered from five percent solids to 40 to 45 percent solids in two to three years using sludge depths of from two to four feet (0.61 to 1.22 meters) (Ref. IV-1).

Pressure Filtration

Sludge dewatering by means of a filter press is a batch operation. Filter plates are usually precoated with either diatomaceous earth or flyash slurry, which reduces filter blinding and provides easy separation of the sludge cake from the filter media, usually monofilament filter cloth. Sludge is pumped into the press, and passes through feed holes along the length of the filter. As the press is closed by either electrical or hydraulic means,

TABLE IV-18

AIR-DRIED DIGESTED PRIMARY SLUDGE CAKE

Quality	Characteristics
Physical texture	Granular friable lumps, about pea size if ground.
Color	Black or dark brown
Odor	Earthy
Solids content	About 40% total solids
Volume	25% to 50% of wet sludge applied.
Volatile matter content	Average range 40 to 55% of the total solids.
pH	6.0 to 6.5 after storage
Carbon, total	28% of dry weight
Nitrogen, total	2.3% of dry weight
Phosphorus, total	0.85% of dry weight

Note: The values for carbon, nitrogen, and phosphorus represent the average of 15 digested primary sludges collected at sewage treatment plants in Connecticut and tested by the Connecticut Agricultural Experiment Station.

Source: Ref. IV-7

water is pressed out of the feed sludge and is discharged through filtrate drain holes. When the filtrate flow is essentially completed, the press is opened and the dried cake is discharged to conveyors or cake hoppers, and the cycle is then repeated. Advantages and disadvantages of pressure filtration are noted in Table IV-19.

The necessity of adding conditioning chemicals to the sludge prior to pressing increases the operating costs and the quantities of sludge to be disposed. "Lime and ferric chloride may add 25 percent by weight of dry solids while preconditioning with ash may add 200 percent of dry solids weight to the sludge" (Ref. IV-2). Heat conditioning may eliminate the need for chemical conditioning; however, difficulties have been noted with sludge cake discharge and high levels of suspended solids in the filtrate (Ref. IV-2). Incineration of the sludge cake can produce a flyash useful in conditioning the sludge applied to the filter press. Typical filter press production data is given in Table IV-20.

TABLE IV-19

PRESSURE FILTRATION CONSIDERATIONS

Advantages	Disadvantages
Higher cake solids concentrations (30 to 50 percent)	Batch operation
Improved filtrate clarity	High labor costs
Improved solids capture	Filter cloth life limitations
Reduced chemical consumption	Operator incompatibility
	Cake delumping

Source: Ref. IV-1

SLUDGE DRYING AND REDUCTION

Sludge reduction processes are generally thermal processes and are intended to reduce the solids required for final disposal or to recover a resource. Table IV-21 indicates the sludge reduction and resource recovery processes discussed in the subsequent sections and in Chapter VI.

Incineration

Combustion by incineration serves as a means of reducing total sludge volume. Because few sludges have a volatile solids content as high as 70 percent, a significant amount of ash will remain after burning. Undigested sludge has a higher heat value than digested sludge, making undigested sludge easier to combust. For sludges with low heat values, supplemental fuel may be added. End products of combustion are usually water, carbon dioxide, sulfur dioxide, and inert ash (Ref. IV-5). The primary methods of incineration are the multiple hearth furnace and the fluidized bed reactor incinerator.

A complete discussion of incineration, particularly in light of resource recovery and reuse, is presented in Chapter VI.

Wet Air Oxidation

Wet air oxidation involves burning of organic matter in the absence of flame and in the presence of liquid water. Temperatures and pressures on the order of 400 to 600 F (150 to 225 C) and 1200 to 1800 psig [pounds per square inch gauge (8.45×10^5 to 12.6×10^5 kg/sqm)] are used for complete

TABLE IV-20

TYPICAL FILTER PRESS PRODUCTION DATA

Sludge Type	Suspended Solids (%)	Conditioning of Dry Solids (%)	Cake Solids (%)	Time Cycle (hr)
Raw Primary	5-10	Ash 100	50	1.5
		FeCl$_3$ 5 Lime 10	45	2.0
Raw Primary with less than 50% EAS	3-6	Ash 150	50	2.0
		FeCl$_3$ 5 Lime 10	45	2.5
Raw Primary with more than 50% EAS	1-4	Ash 200	50	2.0
		FeCl$_3$ 6 Lime 12	45	2.5
Digested and Digested with less than 50% EAS	6-10	Ash 100	50	1.5
		FeCl$_3$ 5 Lime 10	45	2.0
Digested with more than 50% EAS	2-6	Ash 200	50	1.5
		FeCl$_3$ 7.5 Lime 15	45	2.5
EAS	Up to 5	Ash 250	50	2.0
		FeCl$_3$ 7.5 Lime 15	45	2.5

Note: EAS = Excess Activated Sludge

Source: Ref. IV-1

TABLE IV-21

REDUCTION PROCESSES

Reduction Process	Pretreatment Required	Additional Processing Requirements
Established Processes		
Incineration	Thickening and Dewatering	Landfill ash
Wet Air Oxidation	Thickening	Treat cooking liquor, landfill ash
Heat Drying	Thickening and Dewatering	Use dried sludge as soil conditioner
Experimental Processes		
Pyrolysis	Thickening	Utilize by-products of gas, carbon, steam. Dispose of residue
Incineration/ Chemical Recovery	Thickening and Dewatering	Landfill ash. Recover lime from recalcination or heat in power boilers

Source: Ref. IV-1

oxidation of organics (Ref. IV-12). Because it is not necessary to supply energy for the latent heat of vaporization of water, wet air oxidation is particularly applicable for materials like organic sludges which are combustible but cannot be readily separated from water. The problem of ash disposal in the wet oxidation process is somewhat different than in incineration because the ash is conveyed in a significant volume of water. Significant concentrations of nutrients and soluble organic material are contained in the waste liquid portion of the process and should be recycled to the treatment plant or treated in a separate facility. Direct recirculation of untreated liquors to the wastewater treatment plant is estimated to cause a 10-percent increase in the effluent BOD_5 and 20-percent increase in the effluent COD, assuming the capacity is available in the main plant to handle the recycled load (Ref. IV-11). Table IV-22 indicates several values obtained from a pilot scale operation on the liquid effluent, and Table IV-23 indicates an analysis of the ash from the process.

TABLE IV-22

WET-AIR OXIDATION PROCESS EFFLUENT

Volatile Solids Concentration Range (Percent)	Reactor Effluent				Settled Effluent
	NH_3-N (mg/l)	Organic N (mg/l)	Volatile Acids as acetic (mg/l)	COD (mg/l)	COD (mg/l)
2.00-2.99	1,370	368	3,200	10,200	8,300
3.00-3.99	1,625	425	3,480	13,200	9,800
4.00-4.99	1,640	548	3,980	16,600	11,600

Source: Ref. IV-5

TABLE IV-23

TYPICAL ANALYSIS OF ASH FROM WET OXIDATION PROCESS

Parameters	Percent*
Iron (Fe)	4.92
Silicon (Si)	3.78
Potassium (K)	0.76
Manganese (Mn)	0.025
Calcium (Ca)	0.87
Aluminum (Al)	3.90
Zinc (Zn)	0.04
Copper (Cu)	0.24
Magnesium (Mg)	0.03
Phosphorus (P)	2.62
Boron (B)	0.03
Nickel (Ni)	0.01
Sodium (Na)	0.12
Specific gravity	2.23

* Metals determined spectrometrically, percent by weight.

Source: Ref. IV-5

Difficulties with the system include the high organic load exerted by the reactor effluent on the wastewater treatment plant, severe corrosion problems in the oxidation chamber and heat exchanger surfaces requiring frequent maintenance, and accidents with high-pressure steam lines.

Heat Drying

Heat (flash) drying is the instantaneous removal of moisture from sludge solids by introducing them into a hot gas stream.

Wet sludge from a dewatering process is introduced into the dryer with some previously dried sludge and hot gases from the furnace. Drying is essentially completed with the sludge now approximately at 8- to 10-percent moisture. Dried sludge is separated from the spent gases in a cyclone and either sent to fertilizer storage or to the furnace for incineration.

Primary combustion air is preheated in the deodorized gas heat exchanger and introduced into the furnace as combustion of fuel such as gas, oil, coal, or wastewater sludge occurs. Ash accumulates in the furnace bottom and must be periodically removed either by sluicing to an ash lagoon, to a landfill, or to an ash utilization process such as vacuum or filter press operations.

Effluent gases passing through the furnace and combustion air preheater then pass through a dust collector and an induced draft fan to a discharge stack.

Further information on heat drying may be found in Chapter VI.

Pyrolysis

Pyrolysis is the destructive distillation of refuse, sewage sludge, or other organic materials under pressure and heat in the absence of oxygen. Most of the combustion process is carried out within a closed reactor chamber, normally at temperatures lower than in incinerators.

The pyrolysis process has been used on a very limited basis and primarily on municipal refuse rather than sewage sludges. Where municipal refuse has been pyrolized, the products have been gases, pyroligneous acids and tars, and char. The gases consist mainly of hydrogen, methane, carbon monoxide, carbon dioxide, ethane, and ethylene. The pyrolysis of digested sewage sludge yields the same products as those from the solid waste, although the char shows about 70 to 75 percent lower BTU content (Ref. IV-13).

Further information on pyrolysis, the process and its potential for resource recovery, may be found in Chapter VI.

Lime Recalcination

Lime is often used in wastewater treatment as a coagulant for phosphorus removal. It can be applied either as a tertiary step or ahead of the primary clarifiers in either a biological or physical-chemical wastewater treatment plant.

The process of recalcining involves heating the dewatered sludge containing calcium driving off the water and carbon dioxide and leaving the calcium oxide (quicklime). When coagulating raw wastewaters, the inert solid fraction can be removed before recalcination by centrifugation. This inert solid removal must occur to prevent solids buildup within the wastewater treatment process.

Further information on lime recalcination as a resource recovery process may be found in Chapter VI.

PERFORMANCE

A variety of sludge handling and treatment systems have been described, primarily from the viewpoint of presenting information useful in the 208 planning process. System advantages and disadvantages were noted, process sidestreams were discussed in light of their environmental and system upset potential, and possibilities of resource recovery and reuse were presented.

Table IV-24 indicates the normal quantities of sludge produced by different treatment processes. Table IV-25 indicates the sludge processing unit performances where data is available in terms of total solids content of the influent and effluent streams, volume reduction, and solids recovery. The utility of these two tables is in determining the amount of solids to be handled in various sludge treatment processes such that the cost information to follow may be used to obtain first-order cost estimates for planning sludge treatment alternatives. For ease of use, the values in Table IV-24 are given both in pounds of dry solids per million gallons of wastewater and pounds of dry solids per 1000 persons.

ECONOMICS

The unit processes discussed previously for sludge handling and treatment are each characterized by a unique performance under specific influent conditions and effluent requirements. The use of a particular unit process, e.g., centrifugation, in different locations within the treatment train (thickening versus dewatering) or with different types of sludges will result in different equipment and operating requirements. Therefore, the capital and operating costs may vary substantially with the type of application. However, experience gained over time has narrowed down the possible physical arrangements to those more efficient in performance or economical in cost. For example, it is usually impractical both from an operating as well as economic viewpoint to digest sludges before incineration, due primarily to the loss of organic fuel value in the digesting process. It then requires supplemental fuel which costs money to incinerate the digested sludge.

TABLE IV-24

NORMAL QUANTITIES OF SLUDGE PRODUCED BY DIFFERENT TREATMENT PROCESSES*

Treatment Process	Normal Quantity of Sludge			Moisture, %	Specific gravity of sludge solids	Specific gravity of sludge	Dry Solids	
	Gal/ million gal of sewage	Tons/ million gal of sewage	Cu ft/ 1,000 persons daily				Lb/ million gal of sewage	Lb/ 1,000 persons daily
Primary sedimentation:								
Undigested	2,950	12.5	39.0	95	1.40	1.02	1,250	25
Digested in separate tanks	1,450	6.25	19.0	94	---	1.03	750	75
Digested and dewatered on sand beds	---	0.94	5.7	60	---	---	750	75
Digested and dewatered on vacuum filters	---	1.36	4.3	72.5	---	1.00	750	75
Trickling filter	745	3.17	9.9	92.5	1.33	1.025	476	48
Chemical precipitation	5,120	22.0	68.5	92.5	1.93	1.03	3,300	330
Dewatered on vacuum filters	---	6.0	19.3	72.5	---	---	3,300	330
Primary sedimentation and activated sludge:								
Undigested	6,900	29.25	92.0	96	---	1.02	2,340	234
Undigested and dewatered on vacuum filters	1,480	5.85	20.0	80	---	0.95	2,340	234
Digested in separate tanks	2,700	11.67	36.0	94	---	1.03	1,400	140
Digested and dewatered on sand beds	---	1.75	18.0	60	---	---	1,400	140
Digested and dewatered on vacuum filters	---	3.5	11.7	80	---	0.95	1,400	140
Activated sludge:								
Wet sludge	19,400	75.0	258.0	98.5	1.25	1.005	2,250	225
Dewatered on vacuum filters	---	5.62	19.0	80	---	0.95	2,250	225
Dried by heat dryers	---	1.17	3.0	4	---	1.25	2,250	225
Septic tanks, digested	900	---	12.0	90	1.40	1.04	810	81
Imhoff tanks, digested	500	---	6.7	85	1.27	1.04	690	69

* Based on a sewage flow of 100 gpcd and 300 ppm, or 0.25 lb per capita daily, of suspended solids in sewage.

Note:
gal/million gal = liter/1000 cu m
ton/million gal = 240 kg/1000 cu m
lb/million gal = 120 g/1000 cu m
cu ft/1000 persons daily = 0.0283 cu m/1000 persons daily
lb/1000 persons daily = 454 g/1000 persons daily

Source: Ref. IV-7

TABLE IV-25

SLUDGE PROCESSING UNIT PERFORMANCE

Process	Feed	Total solids in	Total solids out	Volume reduction	Solids recovery
		percent weight		percent	
Thickening					
Gravity	Primary	1-3	5-8	50-60	98+
	WAS	0.5-1	2-3.5	50-60	98+
	Primary & WAS	2	4-5	50-60	98+
	Digested primary	2-5	5-8	50-60	98+
	Digested primary & WAS	2-3			98+
Flotation	Primary & WAS	2	5-7	65	95+
	WAS with chem.	0.5-1.5	4-5	65	95+
	WAS without chem.	0.5-1.5	3.5	60	95+
Treatment					
Aerobic digestion	Primary, thickened	5-8	3-5	10	60-65
	Primary & WAS, thickened	4-5	2-4	10	50-60
Anaerobic digestion	Primary, thickened	5-8	2-5	0	40-60
	Primary & WAS, thickened	4-5	2-3	0	50-60
Incineration	Primary, dewatered	25	100	75-85	30-40
	Primary & WAS, dewatered	25	100	75-85	30-40
Wet oxidation	Primary or primary & WAS	4-8	4-8	0	98+
Heat	Any, thickened	4-8	4-8	0	98+
Lime stabilization	Primary, thickened	5-8	5-8	0	110
	Primary & WAS, thickened	4-5	4-5	0	110
Dewatering					
Drying beds	Any, digested	2-5	40	50	98+
	Any, lime stabilization	4-8	40	50	98+
Vacuum filter	Primary, conditioned	2-3	35	90	90+
	Primary & WAS, conditioned	2-3	25	85-90	90+
	Digested, conditioned	2-5	25-37	90	90-95+
Pressure filtration	Digested, conditioned	5-6	30-40	80-90	98+
Centrifuge	Digested	2-5	18-21	60-75	55
	Digested, conditioned	2-5	20-25	75-85	90-95
Heat drying	Digested	2-5	90	95+	98+

Note: WAS = Waste Activated Sludge, same as Excess Activated Sludge (EAS)

Source: Ref. IV-2

The following capital costs were developed from studies by others (Refs. IV-1, IV-2, IV-5, IV-6, IV-7, IV-8, IV-13, IV-14, IV-15, IV-16, and IV-17) having experience with recently constructed facilities, manufacturers' quotes, and other technical literature.

Capital Costs

Capital costs for unit processes are referenced to an Engineering News Record (ENR) Construction Cost Index of 2200, representing mid-1975 costs. The unit prices include basic manufacturing and installation costs, contractor's profit, and a 25-percent allowance for engineering, legal costs, and contingencies. Not included in the prices are the costs of land or the acquisition of rights-of-way.

The following process descriptions and assumptions are used in this report to develop the capital cost curves in Figure IV-1 (Ref. IV-2).

Gravity Thickening

The costs for gravity thickening include thickening tanks and ancillary mechanical and electrical equipment. The design factors are a minimum detention of six hours with a 20 $m^3/(m)^2(day)$ [500 $gal/(ft)^2(day)$] overflow rate.

Dissolved Air Flotation

The air flotation thickening cost curve includes the flotation tank, sludge removal equipment, pressurization system, discharge piping and all other related mechanical and electrical equipment. The air flotation system is sized for a solids loading of 98 kg/m^3 [20 lb $DS/(ft)^2(day)$].

Aerobic Digestion

The aerobic digestion process costs include an aeration tank, mechanical aerators-mixers, piping and valves, ladders and rails, pumping equipment and installation for the transfer of sludge from the thickener. The aerobic digester is sized for a sludge retention period of 15 days, with approximately a six-percent solids content in the liquor.

Anaerobic Digestion

Anaerobic digestion process costs are based upon an assumed solids loading of 3.2 kg/m^3 [0.2 $lb/(ft)^3(day)$]. Costs included in anaerobic digestion are for the digester, floating covers, gas mixing equipment, heat exchangers, gas collection equipment, control building, piping to an on-site location and associated mechanical and electrical equipment.

Incineration

In addition to the incinerator, incinerator building, sludge conveyor and ash handling equipment, the capital costs of incineration include flue gas scrubbing facilities. Incineration costs are based upon a feed sludge with 25-percent dry solids and a multiple-hearth type of incinerator. The fluidized bed incinerator costs include sand costs.

Heat Treatment

The costs of heat treatment are based upon the installation of a Zimpro unit and include a complete oxidation unit, installation, building and foundation and piping for the removal of effluent. The equipment is sized to treat a three-percent solids content sludge with a continuous 24-hour-per-day operation, allowing for a 20-percent down time for maintenance.

Lime Treatment

Chemical stabilization by lime of sludges includes a mixing-thickening tank, a chemical storage tank, air mixer, and chemical feeding equipment. The costs of chemicals are included with the annual operating costs. The chemical treatment system is based upon a lime dosage of 0.1 kg/kg dry sludge solids.

Sand Drying Beds

Installation costs and beds for drying sludges include normal excavation, piping for sludge distribution, sand and gravel drainage beds, and an underdrain system. Mechanical sludge loading equipment and covers for the sand beds are not included. A sludge loading of 0.24 kg/(m)^2(day) [.05 lb dry solids/(ft)^2(day)] is assumed.

Centrifugation

Thickening of sludges with centrifuges requires installation of centrifuges, conveyors, platform and sludge hopper and building. The centrifuge, a solid-bowl horizontal type, is assumed to be operated 16 hours per day, seven days per week, with digested primary and secondary sludge.

Vacuum Filtration

Vacuum filtration costs include either a continuous belt or drum-type vacuum filter, housing, pumps, equipment for chemical conditioning and biological treatment of the effluent. The vacuum filters are loaded at the rate of 49 kg/(m)^2(hr) [10 lbs DS/(ft)^2(hr)].

Pressure Filtration

The dewatering of sludge by pressure filtration involves capital cost items which include vertical plate pressure filters, sludge chemical pretreatment facilities, precoating equipment for the filter plates, pumps, conveyors and controls, and installation within a building.

Operation and Maintenance Costs

The operation and maintenance costs for the unit processes have been related to the average daily weight of dry solids processed and are shown in Figure IV-2. Operating labor is used for equipment start-up, sampling analyses, monitoring, control, and shutdown. Maintenance labor is required for cleaning and repair of process equipment.

Materials incorporated in the costs include expendable materials, chemicals, power for pump and blowers, and replacement sand for sand beds, and fluid bed incinerators. Included in these costs are credit for recovered and recycled energy in direct heat exchange during incineration and indirect internal energy reuse such as recovery of heat from digester off-gas systems.

Labor costs were based on an average hourly wage rate of $4.00 with 25-percent additional fringe benefits. Costs of materials were adjusted to a Wholesale Price Index for Industrial Commodities of 150.

It should be noted that both the capital and operation and maintenance cost curves as presented represent average costs for these solids handling facilities. Care should be exercised in their use, particularly in extrapolation at the low end. Where local cost data is available to the 208 planning agency, it should be used either in lieu of these curves or as verification of their applicability and accuracy.

FIGURE IV-1

CAPITAL COSTS FOR SOLIDS PROCESSING FACILITIES

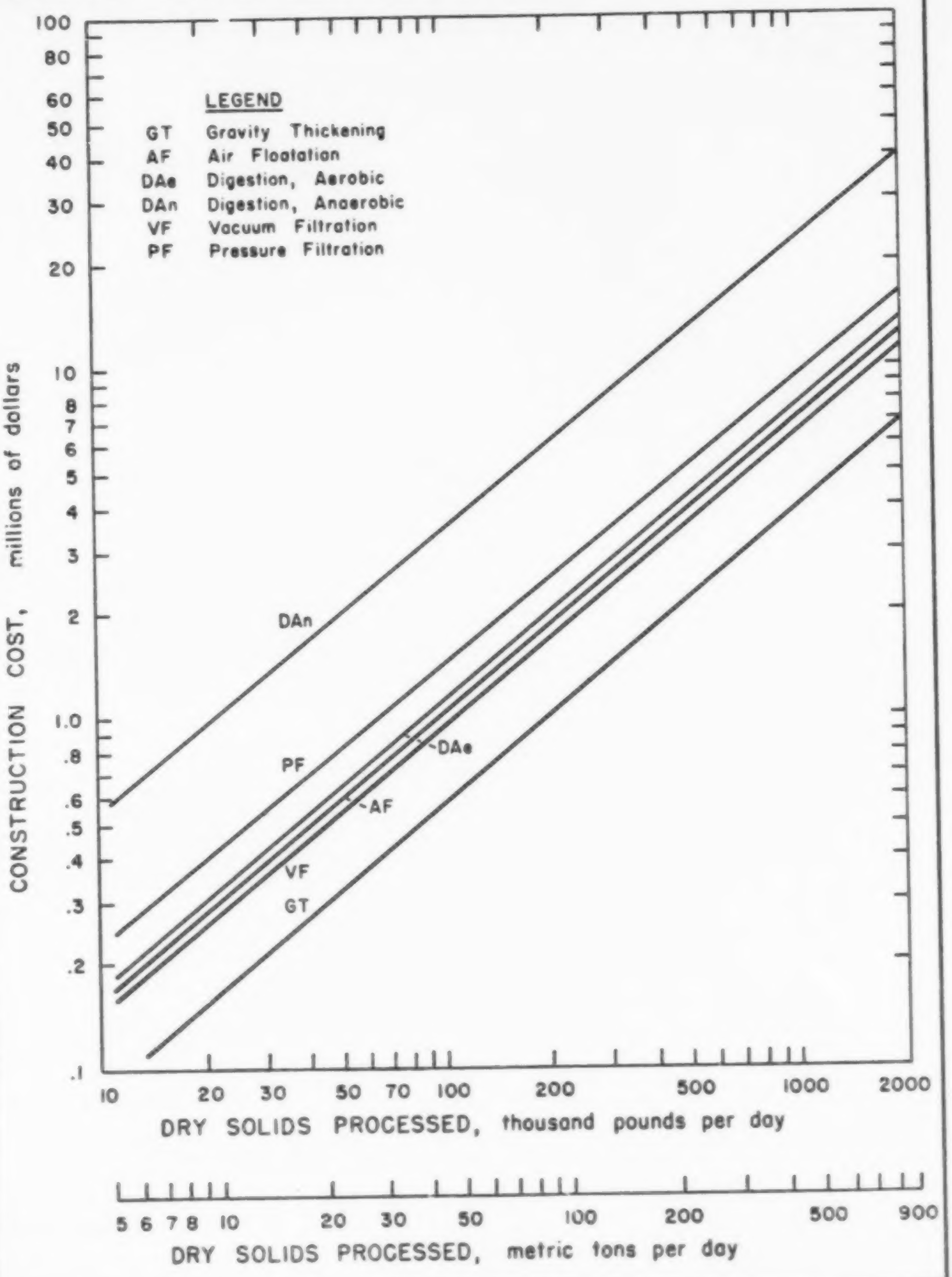


FIGURE IV-1 Con't

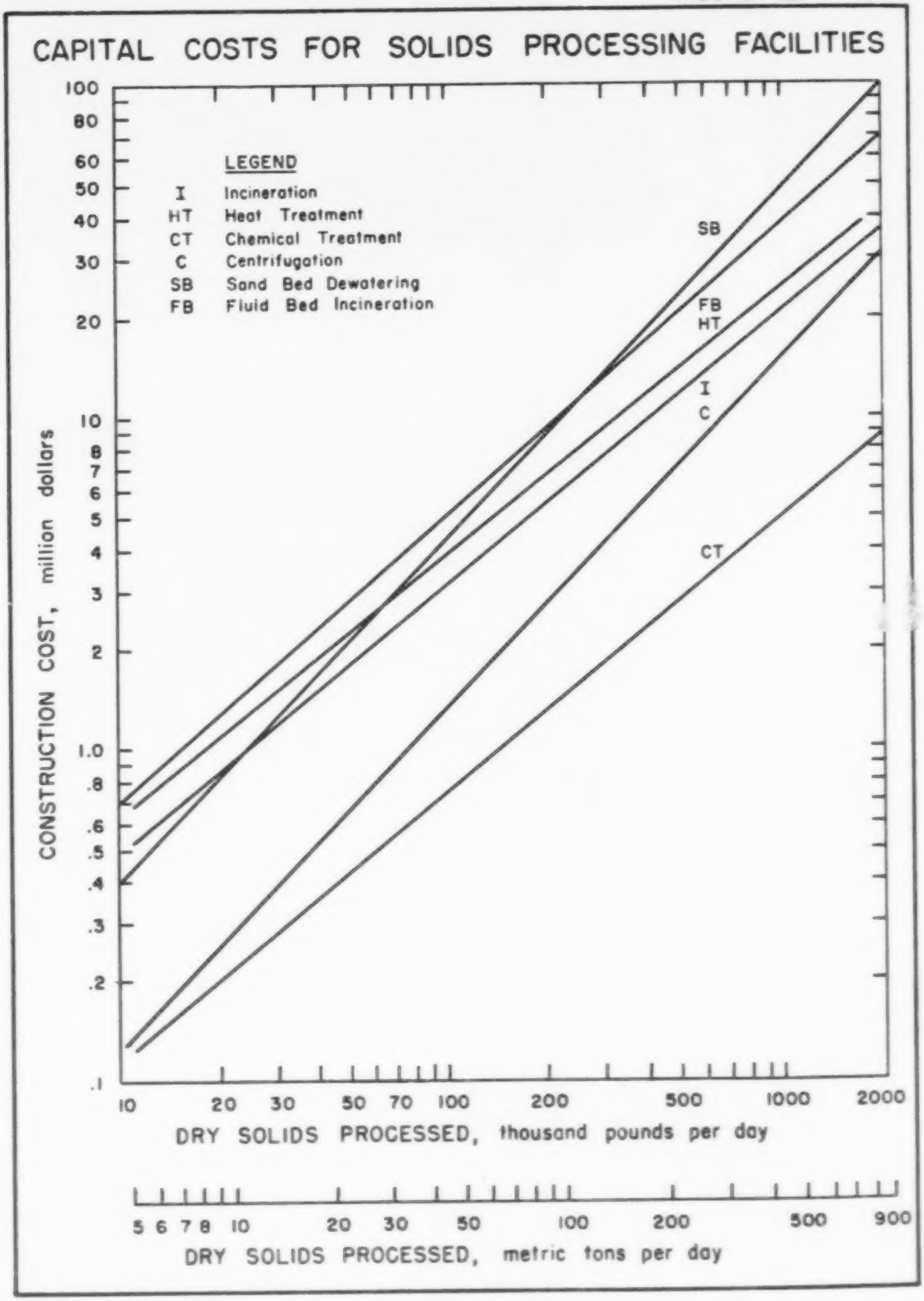

CAPITAL COSTS FOR SOLIDS PROCESSING FACILITIES

FIGURE IV-2

ANNUAL OPERATION AND MAINTENANCE COSTS FOR SOLIDS PROCESSING FACILITIES

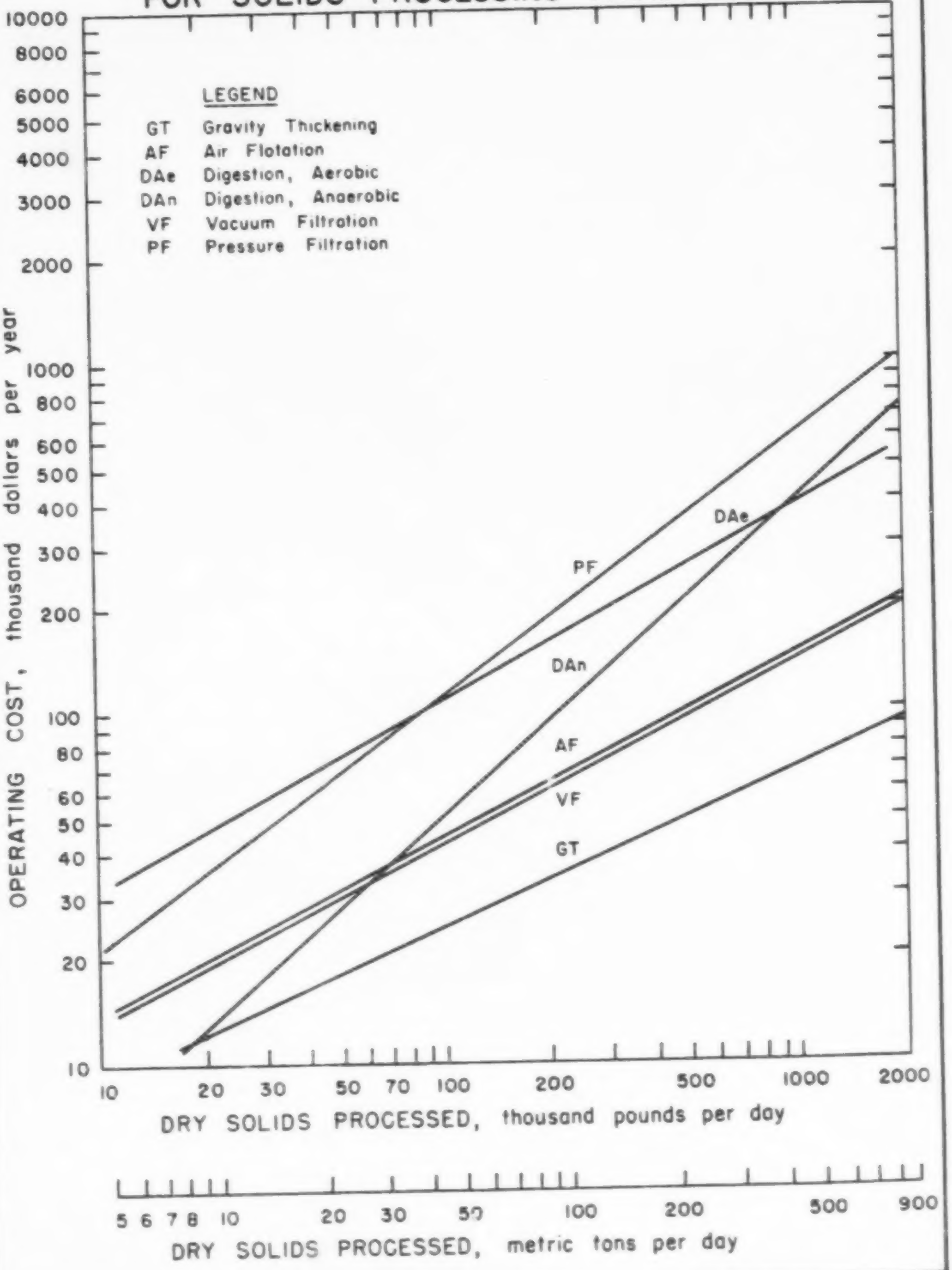
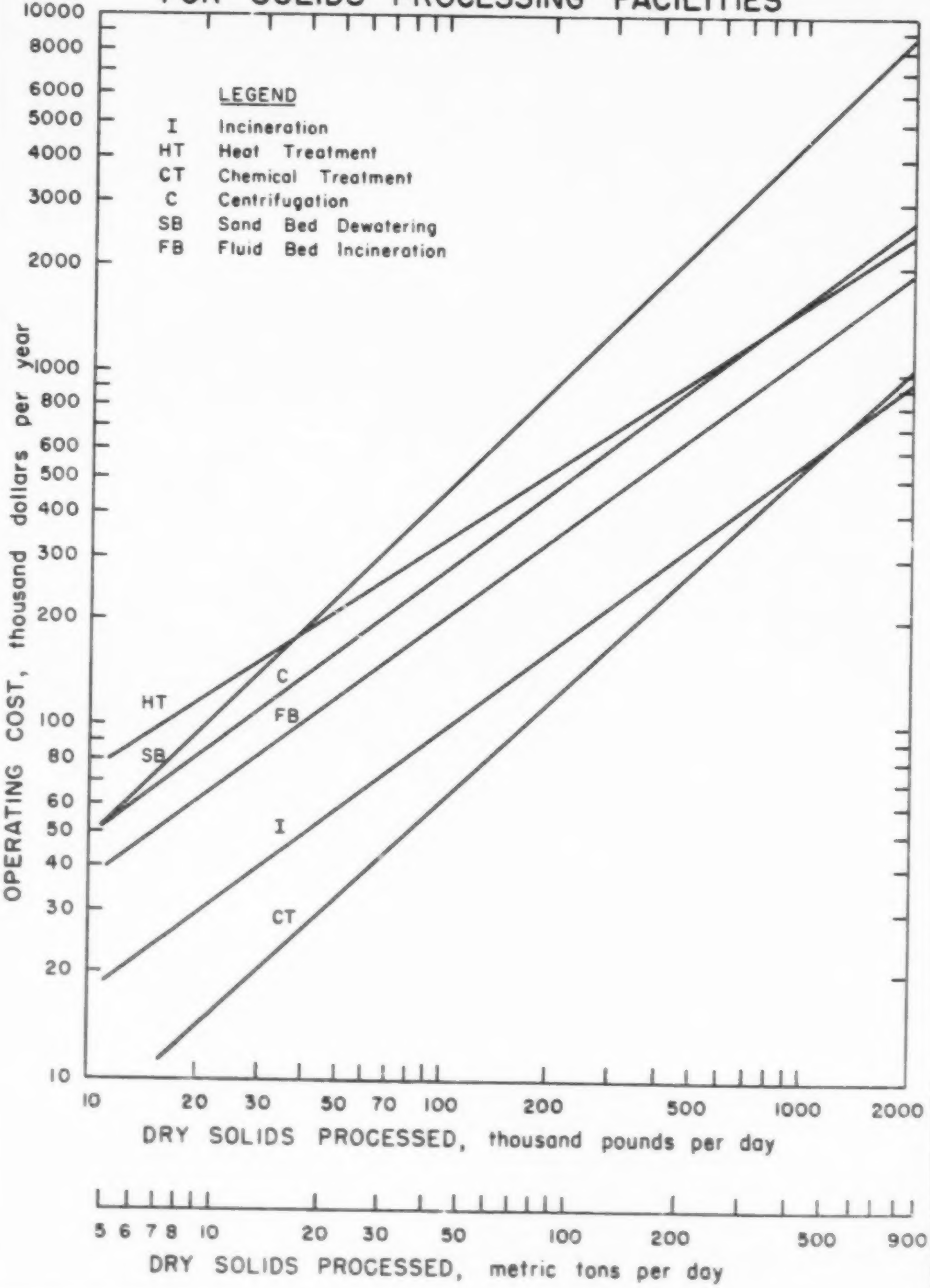


FIGURE IV - 2 Con't

ANNUAL OPERATION AND MAINTENANCE COSTS FOR SOLIDS PROCESSING FACILITIES



CHAPTER IV

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CHAPTER IV

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CHAPTER V

SLUDGE AND RESIDUE TRANSPORT

INTRODUCTION

Sludge handling between unit processes within a wastewater treatment facility is well established and is normally an integral part of the overall design of the facility. The major concerns lie with transport of sludge either to other facilities for further treatment or to an ultimate disposal site. The following sections discuss the pertinent features of the primary modes of transport, namely pipeline, rail, truck, and barge.

PIPELINE

Piping of solids suspended in liquid, including coal, limestone, and sewage sludges, has been practiced for many years as shown in Table V-1. It is also considered practical to batch different solids in the same slurry movement as is done with petroleum products (Ref. V-2).

The hydraulics of sludge flow is complicated because of its varying nature. Below about five percent solids, sludge resembles a fluid with respect to friction considerations and power required for pumping. Above about six percent, power requirements for pumping long distances generally become prohibitive (Ref. V-2).

The velocity of flow during pumping of slurries is an important consideration. Turbulence of flow is necessary to prevent the deposition of suspended solids. Figure V-1 indicates the influence of suspended solids upon minimum velocities required for turbelent flow. For solids concentrations above five percent, required flow velocities are higher than is generally considered economically achievable. However, larger pipe diameters in excess of ten inches can permit higher solid concentrations and still be economically feasible.

Problems can arise in using pipeline transport. Grease can build up on the inside walls of unlined pipe creating a restricted flow. Grit deposited in the pipe during low flow or no flow conditions may cause a temporary increase in the internal pipe roughness.

In the development of pipeline transport systems, consideration must be taken as to the pipeline route and its reliability of service. Where pipeline routes must traverse heavily traveled or recurring construction areas such as metropolitan centers, proper attention must be given to methods of construction, route alignment and rights-of-way, and limited access provisions to insure protection of the pipeline integrity, environmental protection, and minimization of public disruption. Pipeline design must insure monitoring and operational techniques and procedures to anticipate, correct, or ameliorate damage to the pipeline and the surrounding environment due to pipe failure, rupture, or sabotage.

TABLE V-1

SUMMARY OF COMMERCIAL SLURRY PIPELINES

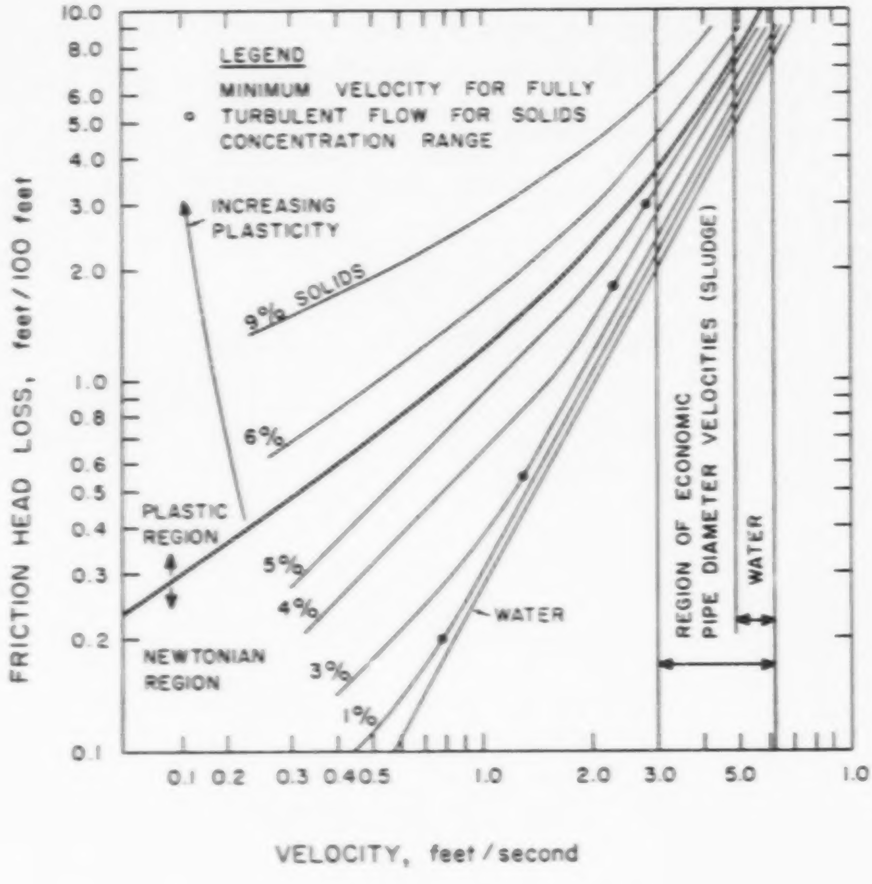
	Location	Material	Length (miles)	Diameter (inches)	Throughput (million tons per year)	Solids Specific Gravity	Weight (percent solids)	Years in Operation or Status
Consolidation Coal	Ohio	Coal	108	10	1.30	1.40	52	6*
American Gilsonite	Utah	Gilsonite	72	6	0.38	1.05	46	11
Rugby Cement	England	Limestone	57	10	0.70	2.70	61	5
Columbia Cement	Columbia	Limestone	9.2	5	0.35	2.70	55	25
South African Companies	South Africa	Gold Tailings	21.5	6 & 9	1.05	2.70	50	14
Savage River Mines	Tasmania	Iron Concentrate	54	9	2.25	4.90	60	2
Black Mesa Pipeline, Inc.	Arizona	Coal	273	18	5.70	1.40	50	In Startup Phase
Hyperion Wastewater Treatment Plant	Los Angeles	Digested Sewage Sludge and Effluent	7.5	22	---	1.80	1.0	11
Mogden Wastewater Treatment Plant	England	Digested Sewage Sludge	7	12	---	1.80	4.0	33
Easterly Pollution Control Center	Cleveland	Raw Sludge	13	12	---	1.60	2.5	32

* Commercial operation ceased in 1963 for non-technical reasons. Now maintained in standby condition.

Source: Ref. V-1

FIGURE V-I

HYDRAULIC CHARACTERISTICS OF SLUDGE SOLIDS



SOURCE: Reference V-2

RAIL

Sludge can be hauled in rail tank cars as a liquid and in either open or closed hopper cars as dewatered solids. At the present time, however, rail haul of sludge is not widely practiced.

Hauling dewatered sludge is similar to hauling coal or ore. Similar loading and unloading facilities and cars may be used. An earlier study has noted that rail transport will become increasingly important in the development of waste management systems (Ref. V-3). Combining dewatered sludge and municipal solid wastes may offer a convenient and economical solution to the disposal of both substances (Ref. V-2). Transporting dewatered sludge in empty coal cars on their return to strip-mined areas may reduce the unit-train costs and provide a greater utilization of rail car and track capacity.

Rail haul rate structures are complicated. Five different rate structures for five geographical areas of the United States exist (Ref. V-2). Rates within these boundaries are not proportional to haul distances nor to the type of material being hauled. Abrupt changes in rate structure and classification may occur at both state and geographical boundaries.

TRUCK

Truck transport of liquid sludges in tank trucks or dewatered sludges and ash in dump trucks is the most common method of transportation used. It provides flexibility of operation in that sludge can either be taken directly to a final disposal site or to an intermediate transfer point such as a railroad yard or barge loading dock.

As with rail transport, truck rate structures and acceptable routes are determined by the Interstate Commerce Commission. What may look to be the most direct route may not be the one allowed. Truck transport must also consider the route from a safety and noise impact standpoint. Substantial truck traffic may be expected to occur when large volumes of sludge must be transported either in a liquid or dewatered state. Truck noise is attributed principally to unmuffled exhausts on diesel engines (Ref. V-4). Consequently, heavy truck traffic must be routed around quiet zones such as hospitals. In addition, routes by areas with heavy pedestrian use such as schools should be avoided.

BARGE

Barging of sludges either in a liquid or dewatered state offers high capacity, but it is a slow means of transportation. Problems, particularly with odors, may occur during storage at dockside prior to barge trips. The Chicago Metropolitan Sanitary District currently hauls 9000 tons (8160 metric tons) of wet sludge per day 188 miles (302 kilometers) down the Illinois River prior to off-loading, storage in lagoons, and spray irrigation on farmland (Ref. V-2).

Table V-2 indicates the type of waste, barge capacity, and discharge characteristics for ocean disposal.

Two types of barges, towed or self-propelled, employing either pumped or gravity discharges may normally be used. The City of New York uses an automated 6300 ton (5700 metric tons) barge 226 feet long, 56 feet wide, and 20 feet deep (69 meters long, 17 meters wide, and 6 meters deep) with an unloading time of 30 minutes. The City of Philadelphia uses an 8000 ton (7250 metric ton) barge hauling digested sludge.

ECONOMICS

Variables affecting the costs are the mode of transport, volume of sludge to be moved, solids content, and transport distance. The total transportation costs include allowances in the case of rail, truck, and barge for operation, maintenance, and fixed charges on loading and unloading facilities as well as the transporting vehicles.

Figure V-2 shows pipeline installation costs as a function of through-put (i.e. pipe diameter) for downtown, suburban, and rural construction. Figure V-3 shows the remaining capital costs as a function of distance transported for various through-put levels. Both figures will then include the total capital costs of the pipeline system such as installation, pipe, pump stations, rights-of-way, and indirect costs. Figure V-4 indicates the annual direct operation costs such as power, labor, supplies, and maintenance as a function of distance for various through-put levels.

Rail costs on both a wet and dry basis are shown in Figure V-5. It should be noted that rail costs could be cut in half were unit trains utilized (Ref. V-2).

Tank truck transportation costs are shown in Figure V-6 for a variety of liquid sludge solids content. Dump truck transport costs of dewatered sludges are shown in Figure V-7 and for ash in Figure V-8.

Barge transportation costs for ocean disposal (capital and maintenance) have been estimated in Table V-3 based upon a figure of $340 per ton representing the purchase cost of newly constructed barges (Ref. V-5 and considering price of materials and labor having risen approximately 200 percent since 1965). Service life of ocean barges varies between ten and twenty years. The primary barge life will be assumed to be ten years, while a secondary standby barge of 1000 ton (908 metric ton) capacity will be twenty years. Annual costs are based upon a seven percent interest rate, equal replacement costs, adn no salvage value. Maintenance costs are assumed to be twelve percent of the annual capital costs (Ref. V-5).

Towing costs are influenced by discharge rate, tug speed and distance traveled. Based upon a rate of $100 per hour, tug speed of six knots (6.9 miles per hour), and an unloading time of 1.5 hours, Table V-4 determines the costs per round trip distance in miles.

TABLE V-2

BARGE CHARACTERISTICS

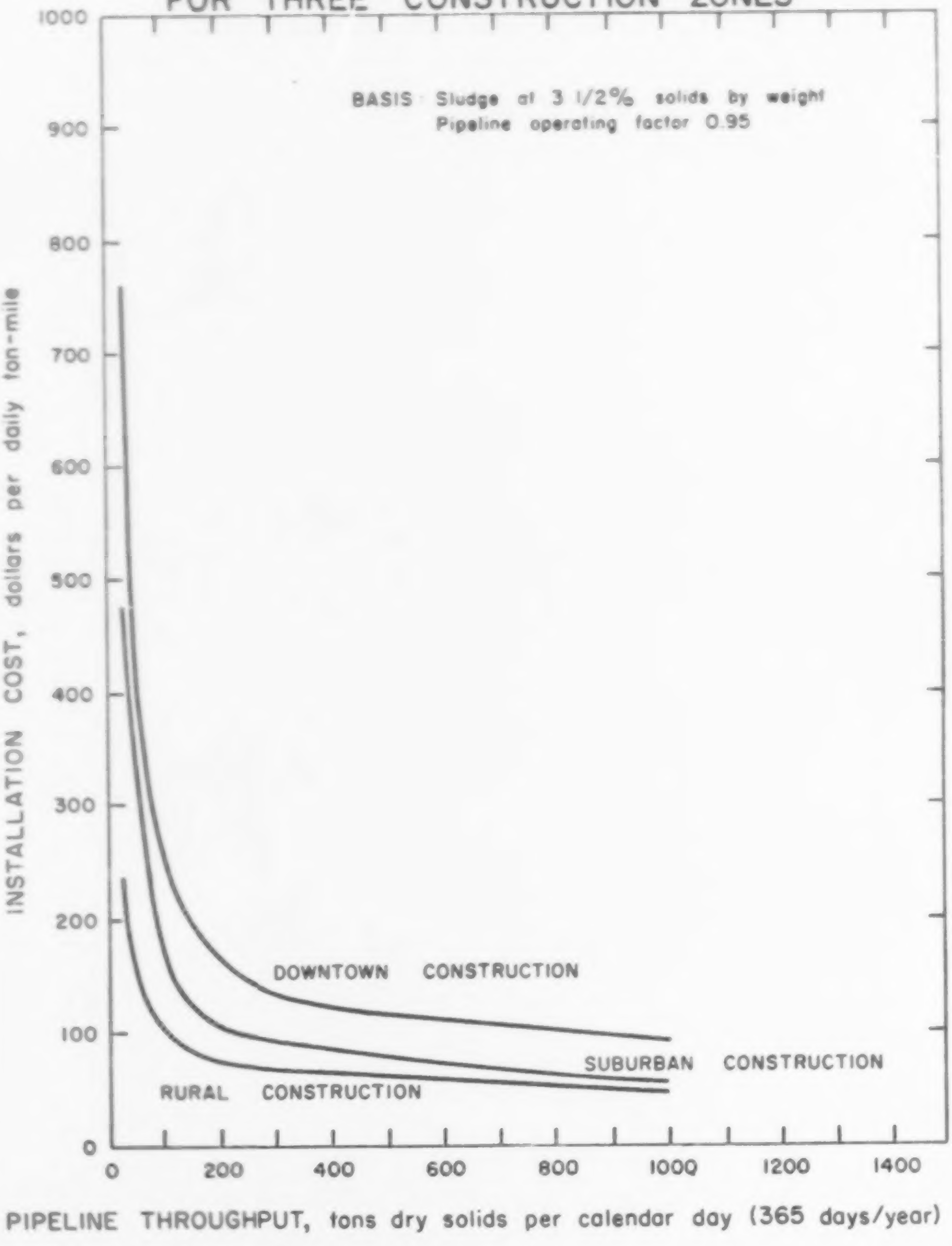
Capacity (Tons)	Type of Waste	Average Depth of Discharge (Feet)	Type	Discharge Characteristics			
				Pipe Size (Inches)	Number Spacing	Towing Speed (Knots)	Discharge Rate (Tons/min)
5,400	Iron-acid	10	Pumped	12	2 @ 50 ft	8.5	78
	Ore washing mud	10	Gravity	--	2 @ 50 ft	8.5	
3,200	Iron-acid	10	Pumped	12	2 @ 43 ft	6.0	16 - 39
5,000	Chem-Insecticides	10	Gravity	--	--	--	--
1,200	Chlorinated Hydrocarbons	12 below deck	Pumped	8	1	6.0	5
1,100	Chlorinated Hydrocarbons	8	Pumped	4	1	6.0	4
8,000	Philadelphia Digested Sludge	--	Gravity	24	8		267
6,300	NYC Digested Sludge	--	--				210
350	Dredge Spoil	17 - 20	Gravity		Bottom dump	--	100 - 200

Note: Feet x 0.3048 = meters
Inches x 2.54 = centimeters
Knots x 1.8532 = kilometers/hr
Tons x 0.9078 = metric tons

Source: Ref. V-5

FIGURE Ⅴ - 2

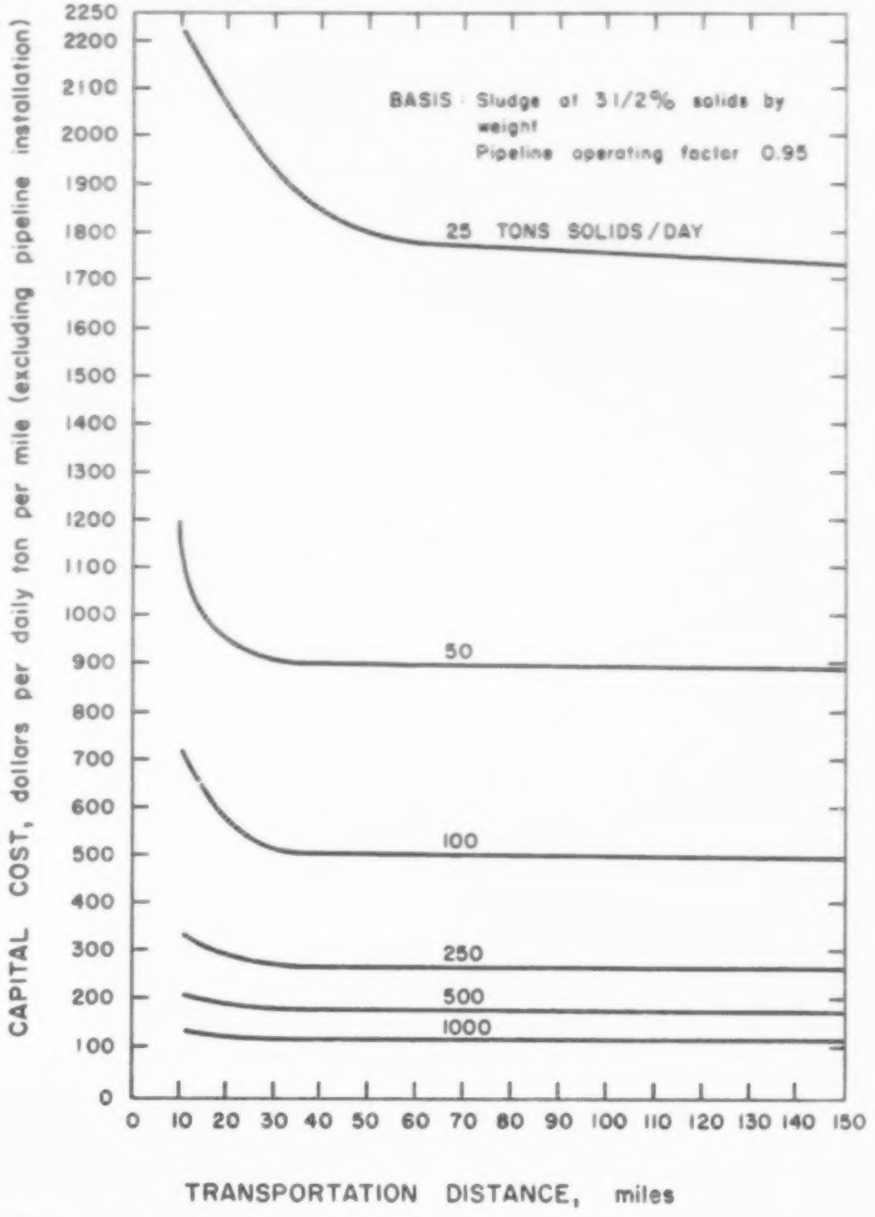
ECONOMICS OF PIPELINE TRANSPORTATION
OF DIGESTED SLUDGE
PIPELINE INSTALLATION COSTS vs CAPACITY
FOR THREE CONSTRUCTION ZONES



SOURCE: Reference Ⅴ-1

FIGURE V - 3

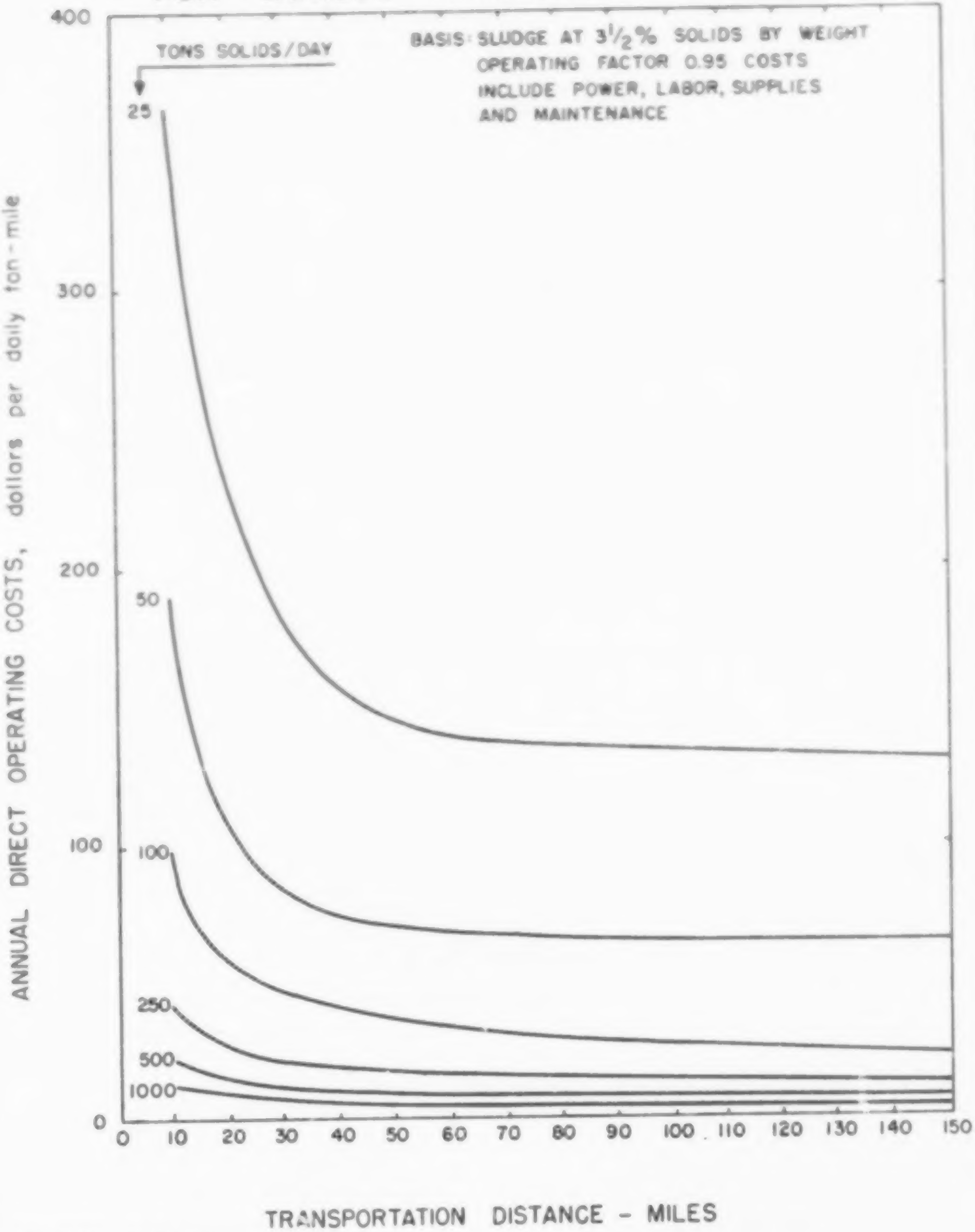
ECONOMICS OF PIPELINE TRANSPORTATION OF DIGESTED SLUDGE
CAPITAL COSTS (Excluding Installation) vs DISTANCE FOR VARIOUS THROUGHPUT LEVELS



SOURCE: Reference V-1

FIGURE V - 4

ECONOMICS OF PIPELINE TRANSPORTATION OF DIGESTED SLUDGE DIRECT OPERATING COSTS vs. DISTANCE FOR VARIOUS THROUGHPUT LEVELS

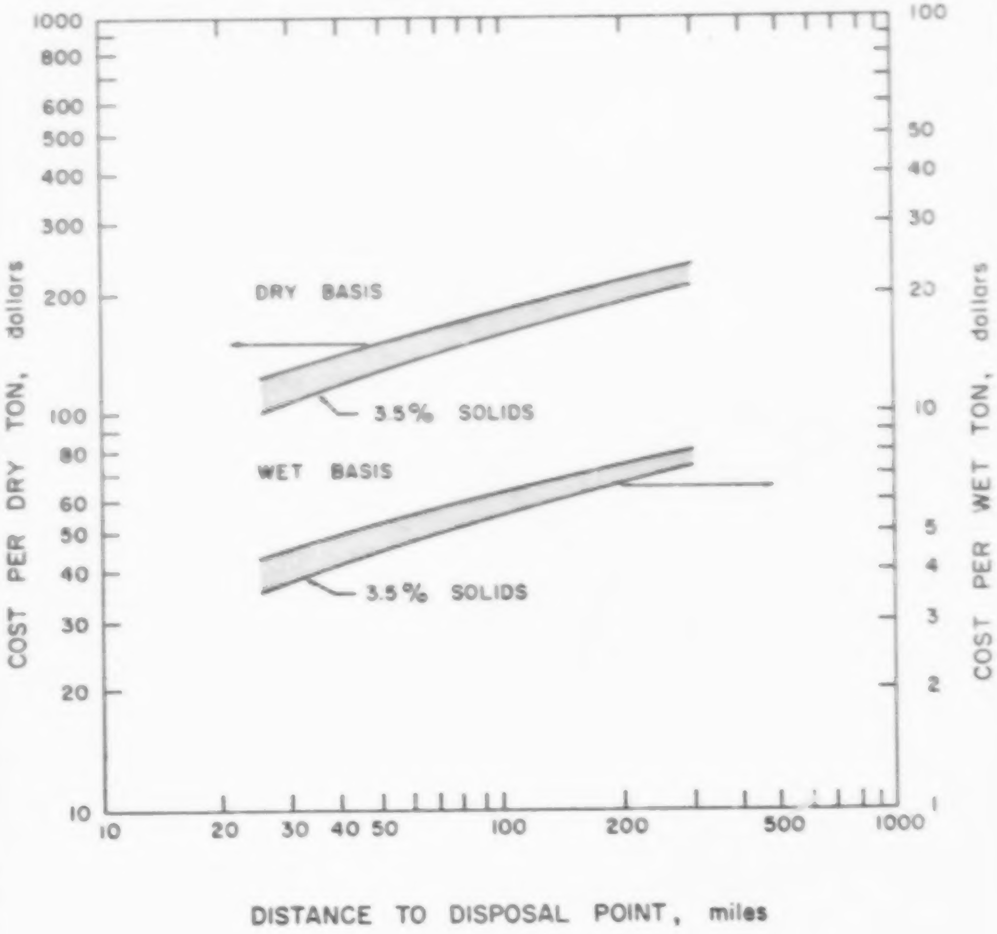


BASIS: SLUDGE AT 3½% SOLIDS BY WEIGHT
OPERATING FACTOR 0.95 COSTS
INCLUDE POWER, LABOR, SUPPLIES
AND MAINTENANCE

SOURCE: Reference V-1

FIGURE V-5

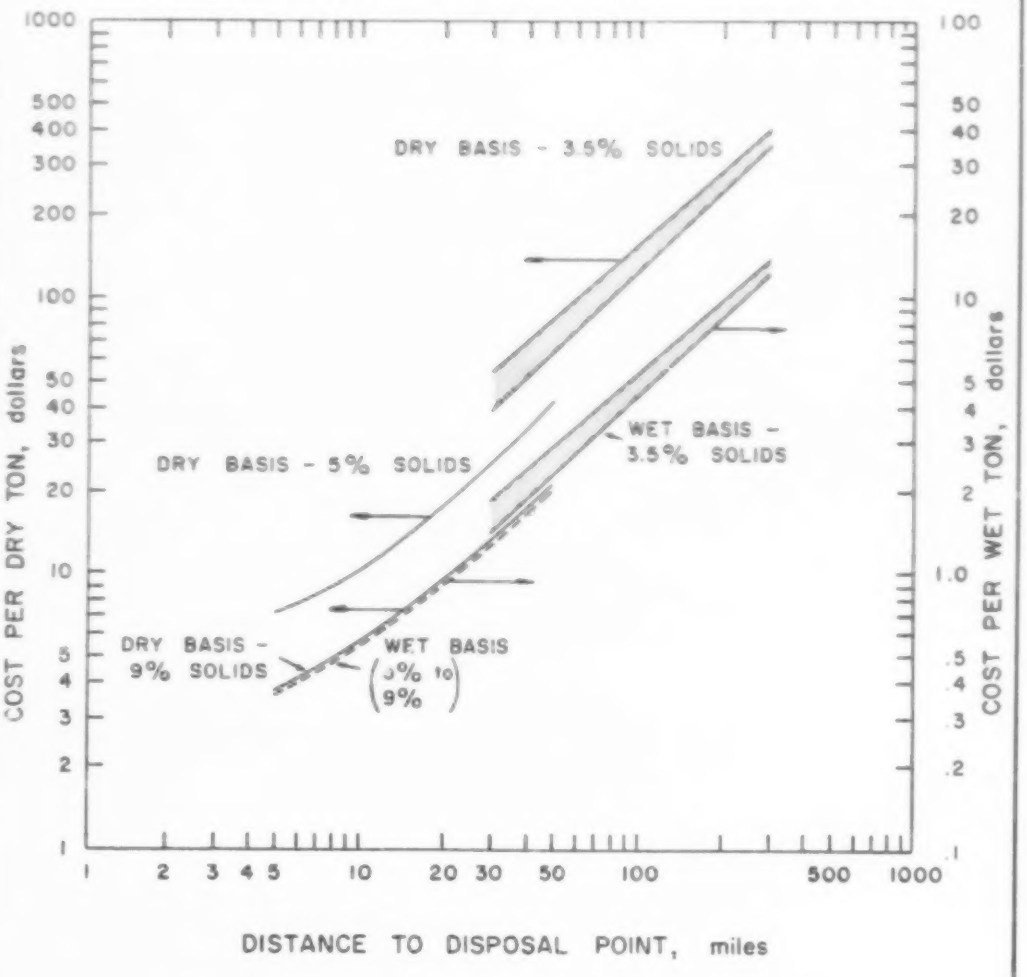
ECONOMICS OF RAIL TRANSPORTATION
(NOT ON A UNIT TRAIN BASIS)



SOURCE: Reference V-2

FIGURE V-6

ECONOMICS OF TANK TRUCK TRANSPORTATION



SOURCE: Reference V-2

TABLE V-3

ANNUAL CAPITAL AND MAINTENANCE COSTS FOR BARGING OPERATION
(Ocean Disposal)

Barge Capacity (tons)	Capital Cost Primary Barge	Capital Cost Secondary Barge	Annual Maintenance Cost	Total Annual Cost
1000	$ 48,409	$ 32,093	$ 9,660	$ 90,162
2000	96,818	32,093	15,469	144,380
3000	145,227	32,093	21,278	198,598
4000	193,636	32,093	27,087	252,816
5000	242,045	32,093	32,897	307,035
6000	290,454	32,093	38,706	361,253

TABLE V-4

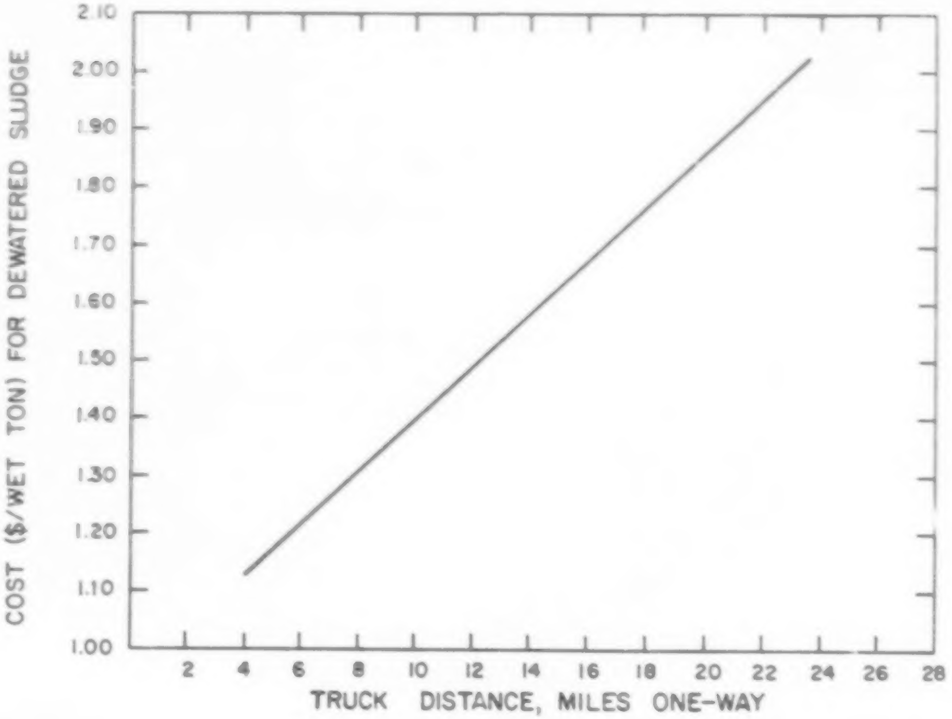
TOWING COSTS FOR BARGING OPERATIONS
(Ocean Disposal)

Round Trip Distance	Towing Costs $/Trip-Mile
10	29.50
25	20.50
50	17.50
100	15.99
150	15.50
200	15.25
300	14.99

Figure V-9 indicates the limiting number of trips per year for barge sizes.

Figure V-10 indicates the costs for inland barging of liquid sludges.

TRANSPORTATION COSTS FOR DEWATERED SLUDGES BY DUMP TRUCK (20-25 CU. YD. CAPACITY) FOR 30% TO 70% SOLIDS (SPECIFICALLY EXPERIENCE AT CHICAGO MSD)



NOTE: Cost Paid To Private Haul Contractors

SOURCE: Private Communication With Mr. Donald Harper of the Chicago Metropolitan Sanitary District

FIGURE V-8

ECONOMICS OF DUMP TRUCK TRANSPORT OF SLUDGE ASH

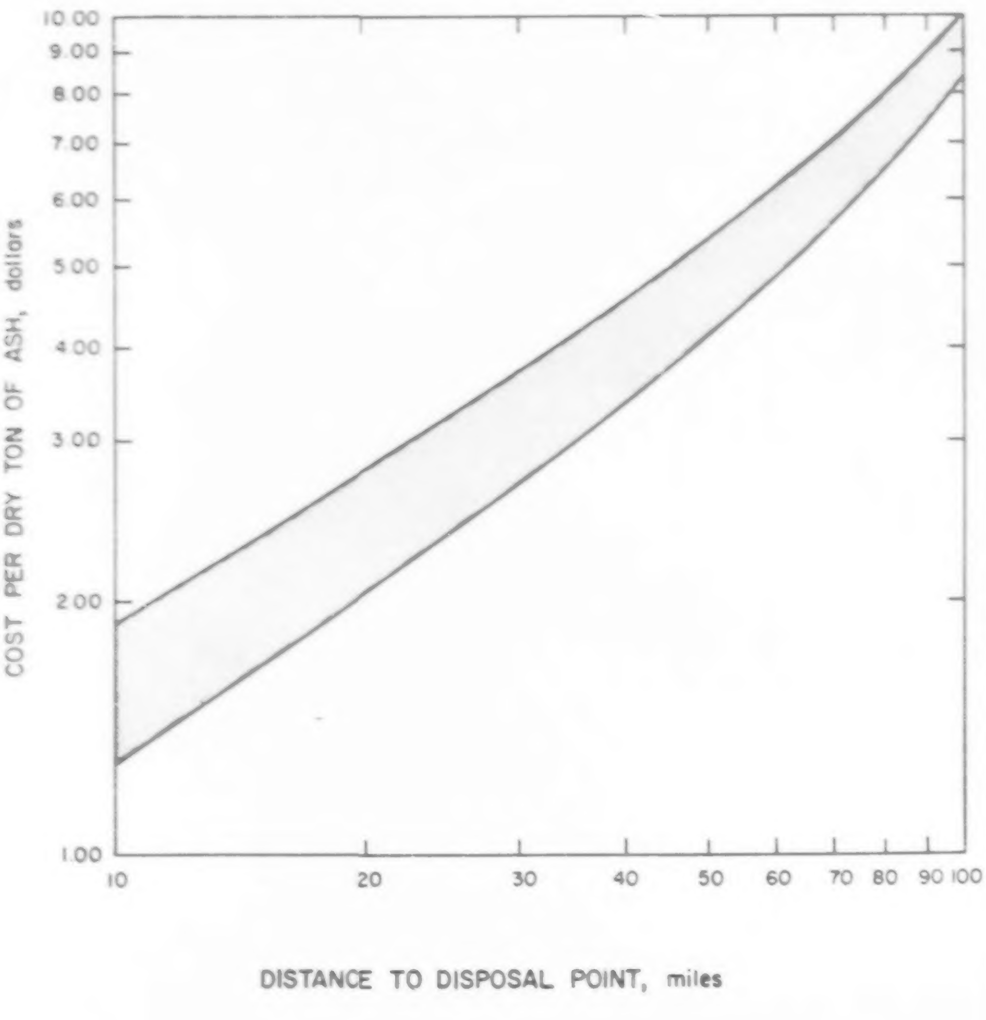
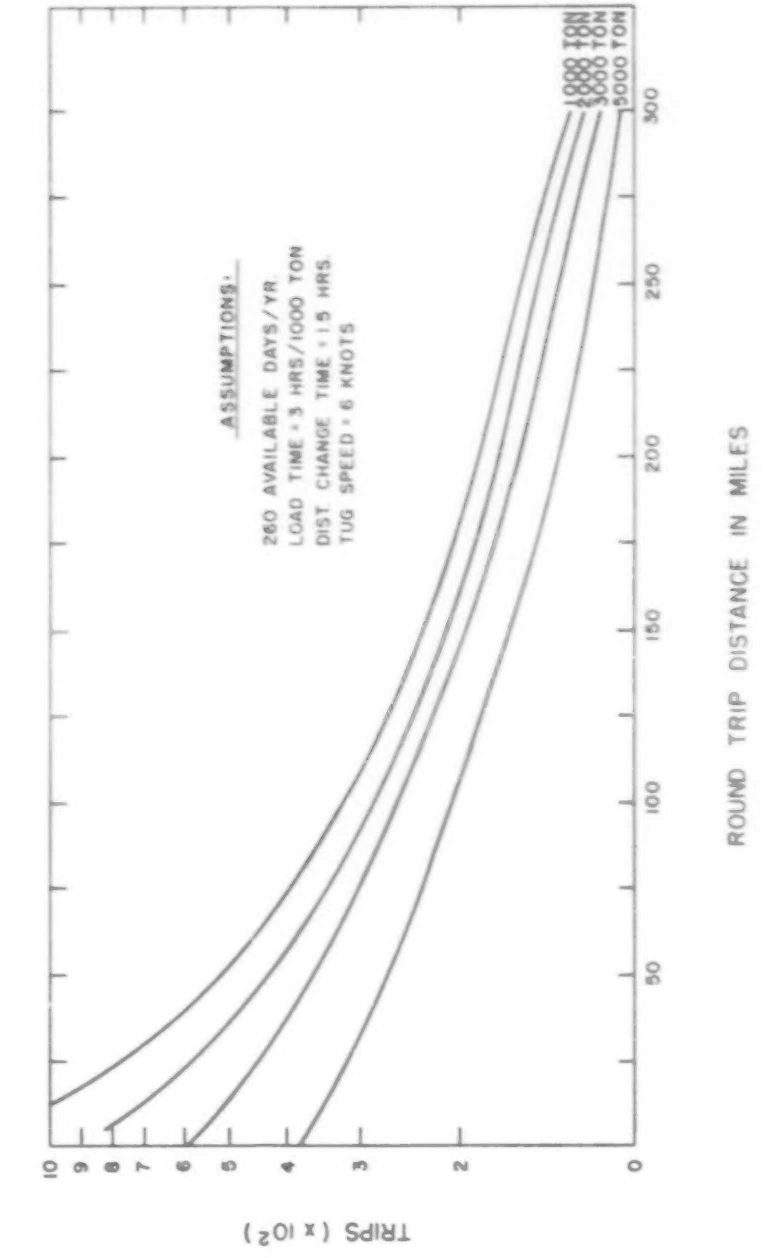


FIGURE V-9

MAXIMUM NUMBER OF TRIPS PER YEAR FOR PRESET BARGE SIZES

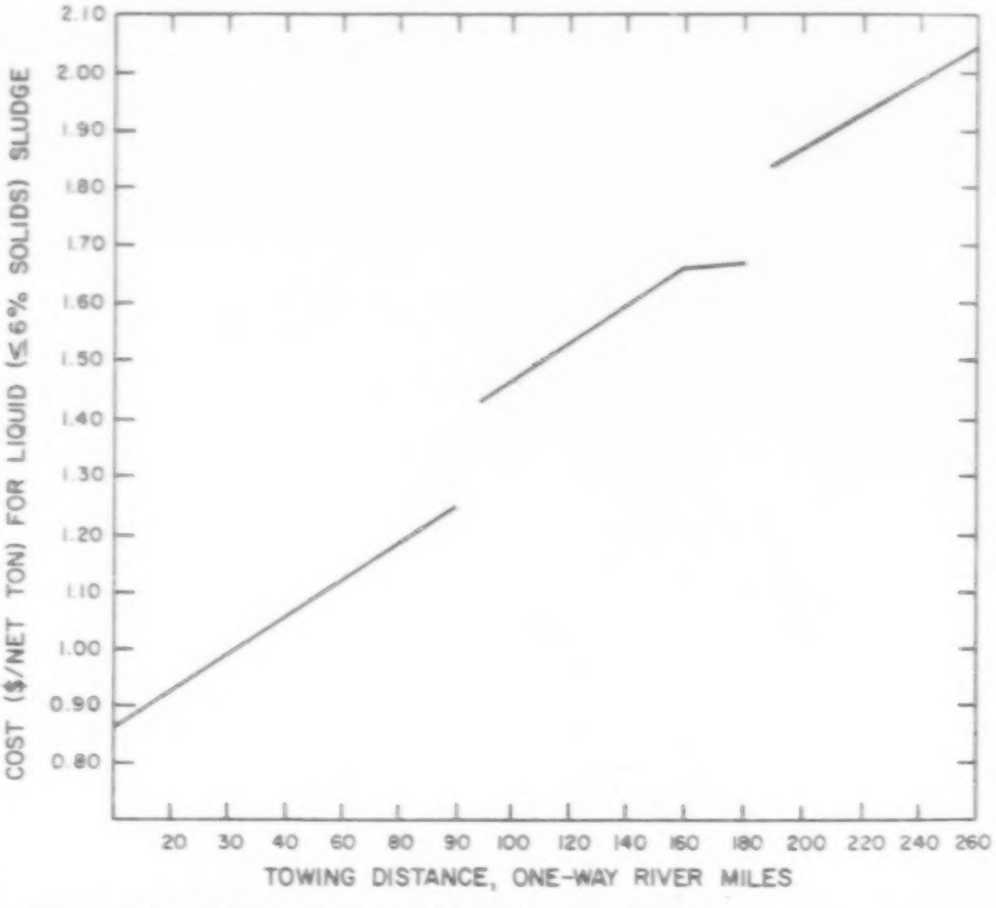


ASSUMPTIONS:

260 AVAILABLE DAYS/YR.
LOAD TIME = 3 HRS/1000 TON
DIST. CHANGE TIME = 1.5 HRS.
TUG SPEED = 6 KNOTS

FIGURE V-10

TRANSPORTATION COSTS FOR LIQUID SLUDGES
BY PRIVATELY OWNED AND CONTRACTED
TOWED BARGE ON INLAND WATERWAYS
(SPECIFICALLY THE TENNESSEE RIVER SYSTEM)



NOTE: Not Included in the Above Costs Are the Following:
1. Dock Structures or Material Handling Facilities
2. Storage at Loading or Discharge Points

SOURCE: Private Communication With Mr. Patrick O Connor of the Tennesse Valley Authority

CHAPTER V

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CHAPTER VI

CHARACTERIZATION OF ULTIMATE DISPOSAL AND RESOURCE/RECOVERY METHODS

INTRODUCTION

Handling of residual wastes must be solved by one of the following routes or combination or routes: (1) elimination of the source of wastes, (2) recycling or by-product use, and (3) disposal to the environment. For municipal wastes, elimination is impossible. Disposal and recycling to the environment remains the most feasible alternative. Therefore, the prime questions become where and how and in what form will municipal residual wastes be reintroduced into the environment. The disposal of municipal residual wastes will ultimately have an impact upon the atmosphere, land, or ocean (realizing that surface water is a transient conveyance mode to the ocean) as ultimate sinks. Ecological and cost considerations, particularly in light of recent and projected energy supply problems, impose increasingly great constraints on ultimate disposal methods. Land disposal of residual wastes, particularly for possible nutrient recovery and reuse, presents an alternative that is receiving much attention. Moreover, it must be recognized that the mass application rate to land surfaces is becoming increasingly greater compared to such convenient sinks as the ocean. This in turn means that land area may become limiting. Well-engineered marine disposal systems have been constructed and have proven successful. Ocean outfall diffusers in use on the West Coast provide very high dilutions and have shown little, if any, adverse effects upon the ocean environment. However, poorly designed ocean dumping systems exceeding the ocean site capacity may significantly degrade the ocean site and its utilization as a food supply and recreational area.

The purpose of this chapter is to provide a technical background for the ultimate disposal methods considered in this report. These methods include: (1) sanitary landfills, (2) sludge recycling, (3) land reclamation, (4) waste disposal ponds, and (5) ocean disposal. Moreover, in this chapter the characteristics of residual wastes are evaluated relative to the various aspects of the ultimate disposal methods. It is perceived that the combination of general technical background and specific application of the disposal methods to municipal wastewater wastes will provide a comprehensive view of the disposal problem of such wastes.

Disposal of residual waste may not be necessary when an economical use for the sludge exists, either directly or indirectly by sludge processing with product recovery. The total cost of the wastewater treatment system may be reduced when sludge becomes a profitable commodity. In viewing sludge as a resource, the resource recovery methods discussed in this chapter are: (1) incineration, (2) pyrolysis, (3) lime recalcination, (4) composting, and (5) sludge reuse.

Each disposal method is discussed separately with topics covering historical and institutional perspectives both past and present, and general operational procedures used in the disposal method. In addition, the waste characteristics pertinent to the disposal method are discussed and contrasted to those of various municipal residual waste types. Siting criteria, environmental effects, monitoring provisions, institutional constraints, management agency control and monitoring programs, and costs are also discussed within each section relative to the disposal of these wastes by the particular disposal method. Finally, the ultimate disposal methods are compared to each other according to various socioeconomic, environmental, and operational criteria.

SANITARY LANDFILLS

Introduction

A sanitary landfill has been defined as "...a method of disposing of refuse on land without creating nuisances or hazards to public health or safety, by utilizing the principles of engineering to confine the refuse to the smallest practical volume, and to cover it with a layer of earth at the conclusion of each day's operation or at such more frequent intervals as may be necessary" (Ref. VI-1). The primary objective of any solid waste disposal process is to reduce the volume of the refuse in order to maximize the storage capacity of the site (Ref. VI-2). In sanitary landfilling, volume reduction is done initially by the mechanical compaction of the refuse prior to its burial. As the landfill ages (i.e., degrades), further volume reductions occur as a result of overburden-induced densification and removal of materials by gas and leachate production. Properly operated sanitary landfills can reduce municipal refuse volume by two-thirds (Ref. VI-2).

Municipal refuse is a complex heterogeneous collection of substances which can and, in some cases, does include sewage and water treatment sludges. Current EPA guidelines on land disposal are modeled after sanitary landfill operational and design characteristics, with a strong emphasis on the minimization of environmental impacts during and after disposal operations (Ref. VI-3). Existing and proposed state and local guidelines on land disposal (open dumping) of solid wastes, in general, are in keeping with those of EPA; and, over the long run, sanitary landfills can be expected to predominate.

There are many advantages associated with using the sanitary landfill method of disposal of solid wastes compared with other methods such as incineration or ocean dumping. The Bureau of Solid Waste Management (1969, now of EPA) has cited the following as advantages of a sanitary landfill:

(1) where land is available, a sanitary landfill is usually the most economical method of solid waste disposal;

(2) the initial investment is low compared with other disposal methods;

(3) it is a complete or final disposal method as compared to incineration and composting which require additional treatment or disposal operations for residue, quenching water, and unusable materials;

(4) it can be put into operation within a short period of time;

(5) it can receive all types of solid wastes, eliminating the necessity of separate collections;

(6) it is flexible and increased quantities of solid wastes can be disposed of with little need for additional personnel and equipment; and

(7) submarginal land may be reclaimed for use.

The disadvantages cited by the Bureau include:

(1) in highly populated areas, suitable land may not be available within economical hauling distance;

(2) proper sanitary landfill standards must be adhered to daily or the operation may result in an open dump;

(3) sanitary landfills located in residential areas can result in extreme public opposition;

(4) a completed landfill will settle and require periodic maintenance;

(5) special design and construction must be utilized for buildings constructed on completed landfill because of the settlement factor; and

(6) methane and other gases produced by decomposition of the wastes may become a hazard or nuisance problem and interfere with use of the completed landfill.

The principle disadvantages of sanitary landfilling are associated with the aging or long-term degradation of the fill. Subsidence and methane gas production limit the reuse possibilities of the site for many years after disposal operations are completed. Sewage sludges introduced into a sanitary landfill can be expected to contribute significantly to these problems.

Operational Characteristics

There are three general types of sanitary landfill construction, their applicability largely dependent on topography and cover material availability.

(1) The trench method (trench-fill or cut-and-cover method) is used in areas of flat or gently sloping topography. This method generally requires that the site can be trenched with conventional earth-moving equipment and that water-table levels be at least lower than the depth of cut. When completed, the landfill consists of a series of long, narrow cells in parallel rows. Cover material is obtained on site from the excavation of adjacent trenches. The finished grade is usually higher in elevation than the original ground surface.

(2) The area method (area-fill or fill-and-cover method) is used in low lying areas, such as tidelands, marshes, or swamps, and in land depressions such as abandoned quarries, ravines, or canyons. Refuse is dumped on the existing ground surface, spread in horizontal layers, and compacted. Cover material is provided by excavation of the earth in front of the working face of the landfill or, if excavation on-site is not possible, by importation of earth from another location. The finished fill consists of a series of cells in layers and results in a significant increase in the surface elevation of the site.

(3) The ramp method (progressive-slope method) is used exclusively in filling natural or man-made depressions (e.g., ravines, canyons, quarries, etc.). Refuse is deposited and spread in layers at an angle against the side of the depression to a design height which can be greater than 15 meters (50 feet). Cover soil is placed on the slope sides and top at regular intervals.

Waste Characteristics

There have been significant changes in the proportionate amount of the types of waste which have been introduced into sanitary landfills. The widespread use of garbage grinders has decreased the amount of garbage (i.e., putrescible refuse) collected as solid waste while increasing the organic loading at sewage treatment facilities, resulting in greater sludge quantities. The increased use of throw-away paper, plastic, and glass containers has led to increases in this type of refuse (Ref. VI-4).

The key characteristics of refuse (including sewage sludge) during the operation of the sanitary landfill are its compactability and its bearing strength. The mechanical compaction of the refuse by large bulldozers is an important step in maximizing the available storage capacity of the site and minimizing the effects of subsidence. The bearing strength of the refuse determines in large part the type of landfilling which can be done. Refuse with an overall low bearing strength such as wet sludge solids will not be amenable to ramp-type landfilling operations as relatively low-angle slopes will fail under minimal loads. Table VI-1 (Column 2) shows the general character of various types of refuse in sanitary landfills. Because of the operational difficulties and volume requirements encountered with liquid sludges, general practice has preferred that sewage sludges be dewatered (10-15 percent dry solids). However, even dewatered sludges have poor engineering properties in that they are largely incompressible and have little bearing strength. Consequently, special operational techniques such as trenching or mixing with large quantities of refuse must be utilized for sludge disposal. Over time, the dewatering of the sludge will add significantly to landfill subsidence.

TABLE VI-1

CLASSIFICATION OF SANITARY LANDFILL MATERIALS

Material (1)	Character in Fill (2)	Deterioration (3)
Garbage	Wet, Compressible, Weak	Decay with Noxious Gas
Fibrous Organic: Wood Paper	Compressible	Decay with Methane Formation
Tires	Very Resilient	Will burn
Small Metal: Cans, etc.	Can be Compacted	Rust and Galvanic Action
Large Organic: Stumps	Resist Compaction	Will burn, decay, and generate methane
Large Metal	Resist Compaction, Loose Compressible	Rust followed by collapse
Building Debris	Compressible and can be Compacted	Little or none
Ashes	Compressible, Weak	Aggravate Corrosion

Source: Ref. VI-5

Table VI-1 (Column 3) also shows the degradation effects of the various types of refuse. Sewage sludges would be expected to degrade in a fashion similar to garbage and fibrous organic material such as paper. Consequently, sludges would contribute significantly to methane gas production. Leachate production, at least initially, would be expected to increase as the sludges dewater.

EPA guidelines currently recommend that sewage treatment sludges be dewatered before being placed in a sanitary landfill. The guidelines state further that sewage sludges be digested (or some equivalent treatment) in order to reduce both operational and public health hazards associated with biological wastes (i.e., fecal coliform bacteria and viruses). Raw sewage sludges are classified as hazardous wastes under the EPA guidelines and require special investigation before disposal is allowed (Ref. VI-3).

Siting/Environmental Considerations

Site selection criteria for a sanitary landfill include technical, socioeconomic, and environmental considerations. The following is a representative list of such criteria (Ref. VI-4, VI-6, and VI-7):

(1) Costs - Land values of the candidate landfill sites should be compared by their present values in the community, potential uses, and possible degradation of neighboring lands.

(2) Land Requirements - Sufficient land should be available to meet the volume requirements of the service population for a reasonable number of years.

(3) Land Use Compatibility - Candidate sites should comply with local zoning regulations and planning documents.

(4) Accessibility - Candidate sites should have two or more all-weather access roads.

(5) Character of the Land - The land at the site should not be so rocky or swampy that equipment might be damaged or bogged down when filling operations are attempted. Other natural conditions which should exclude a site from consideration (unless specifically designed for) are:

(a) hilltops and ridges,

(b) highly porous areas,

(c) swamps and marshes (except under a reclamation scheme),

(d) natural drainage channels,

(e) wildlife sanctuaries, and

(f) flood plains

(6) Aesthetic Considerations - It is very important that a sanitary landfill site does not constitute a public eyesore, especially to residents of nearby housing. Odor and machine noise from sanitary landfills can cause aesthetic objections. A distance of at least 300 meters from the nearest highways and other thoroughfares should be maintained unless adequate shielding by natural barriers (land formations, streets, etc.) or man-made structures are present. Sanitary landfills should be located downwind from areas of human activity and residence whenever possible to avoid odor and noise nuisance.

(7) Availability of Cover Material - A suitable and adequate source of cover material should be available at the site or at an economical haul distance from the site. The ideal cover material is sandy loam (50-60 percent sand, 20-25 percent silt, 20-25 percent clay). However, any well-graded soil with good composition and low shrinkage properties is suitable.

(8) Haul Distance - Landfill sites should be located where they are closest to the sources or refuse within the ranges dictated by other site selection criteria. Where a regional or inter-service landfill is used, it should be located equidistance from all the stations served inasmuch as practicable. Where long-haul distances are made necessary (over about 9 kilometers, 5.6 miles), use of large trailer trucks or railcars as well as transfer stations may become necessary. One large site should be favored over a number of small sites even if the former may require slightly higher haul expense.

Resources that are utilized or may be impacted by disposal or residual wastes such as sewage sludges and incinerator ash to sanitary landfills include:

(1) Water Quality - Without adequate design measures to mitigate leaching and surface runoff, residual waste disposed to sanitary landfills may cause:

(a) degradation of subsurface and surface water supplies by leachates;

(b) degradation of surface water supplies by runoff; and

(c) chronic deterioration of ecological conditions in receiving waters.

(2) Air Quality - Nocuous and potentially hazardous gas (methane) may be exposed and dissipated to the atmosphere after discharge. Possible impacts on air resources include the following:

   (a) methane gas produced after abandonment may collect beneath a structure subsequently built on top of the old disposal site, thus producing a potentially hazardous (explosive) situation;

   (b) sludge is mixed with refuse before disposing to a sanitary landfill so that a potential fire hazard is constituted. Burning waste would cause smoke emission to the atmosphere, thus degrading ambient air quality;

   (c) during the daily application of soil cover, dust may be generated which will deteriorate air quality; and

   (d) inhabitants of the surrounding area are susceptible to possible noxious odors from the sanitary landfill.

(3) Land Quality - Possible impacts upon land-related resources include:

   (a) prevention of other surface land use by occupation of surface area by the disposal facility;

   (b) clearing the land necessary for the landfill may allow immediate erosion to occur;

   (c) operation of the sanitary landfill by continually exposing fresh soil during daily application of cover may allow erosion to occur; and

   (d) leaching through the bottom and sides of the landfill may deposit contaminants in the soil beneath and adjacent to the landfill's perimeter.

(4) Public Health - Possible impacts upon public health considerations include:

   (a) the presence of toxic substances and pathogens in some residual wastes might damage public health if pathogens and/or toxic substances contaminate subsurface water supplies directly by leachates or surface water supplies by lateral groundwater transport of leachates to surface waters;

   (b) agricultural cultivation subsequent to abandonment of the disposal site could produce crops that have incorporated toxic substances in edible portions of the plant;

(c) vectors of pathogens (e.g., insects and rodents) may be attracted to the disposal site which could allow dissemination of pathgens to populations in the surrounding area;

(d) the presence of accidentally burning refuse at the disposal site could present a fire hazard to the contiguous area; and

(e) dust and smoke from the site could possibly pose a health problem to local residents.

Besides the hydrologic effects of increases in surface elevation, changes in soil character, and the potential of on-site water ponding, the degradation of the refuse (and sludges) within the landfill may have serious potential impacts on the environment. Continuous long-term settling along with organic decay and subsequent leaching may cause the sanitary landfill to subside as both density increases and material is removed. Subsidence occurs unevenly and unpredictably within a fill owing to the different times of cell completion and the unique composition of each cell (Ref. VI-8).

The leachate issuing from the landfill consists of very high concentrations of organic and inorganic compounds; values of NH_4-N = 320 mg/l, total nitrogen = 5357 mg/l, BOD_5 = 77,050 mg/l being reported (Ref. IV-9). Few published data are available on the bacteriologic quality of landfill leachate, but it is believed to be poor. Coliform counts of up to 7×10^6 per 100 millimeters on a simulation study (Ref. VI-10) and 7.4×10^5 per gram of refuse at a landfill (Ref. VI-9) have been reported. Depending on the local hydrogeologic conditions, the leachate can pollute potential or existing groundwater or surface water supplies.

Air does not penetrate a well-compacted landfill to any extent. As a result, the organic material in a landfill decomposes anaerobically and produces carbon dioxide, methane, and other gases. Much of the carbon dioxide dissolves in the infiltrating water causing it to become weakly acidic, and it is the first step in the production of the highly-concentrated leachate. Methane tends to escape from the surface of the fill or through adjacent lands. Closed structures (e.g., buildings) on or near the site can trap methane which is explosive at relatively low concentrations (5-15 percent).

Suitability of Disposal

Municipal residual wastes differ greatly in their suitability for disposal by the sanitary landfill method. Table VI-2 compares a representative list of residual wastes against four basic evaluative categories: (1) operational constraints, (2) institutional restraints, (3) potential for leachate contamination, and (4) methane production. The qualifiers of low, moderate, and severe are used only to indicate the relative differences between the different types of residual waste.

TABLE VI-2

SUITABILITY OF VARIOUS MUNICIPAL WASTEWATER TREATMENT PLANT RESIDUAL WASTES FOR SANITARY LANDFILL DISPOSAL

Residual Waste	Operational Constraints	Institutional Constraints	Potential Groundwater Contamination	Methane Production
Biological Treatment				
Primary Sludges				
Undigested	Severe	Yes	High	High
Thickened	Severe	Yes	High	High
Digested	Severe	No	High	High
Activated Sludges				
Undigested	Severe	Yes	High	High
Thickened	Severe	Yes	High	High
Digested	Severe	No	High	High
Sludge Cake	Moderate	No	High	High
Ash				
Wet Oxidation	None	No	Low	None
Incineration	None	No	Low	None
Chemical Treatment				
Alum Sludge				
Raw	Severe	No	Moderate	Low
Dewatered	Moderate	No	Moderate	Low
Lime Sludge				
Raw	Severe	No	Moderate	Low
Dewatered	Moderate	No	Moderate	Low

Operational constraints for a sanitary landfill relative to the residual waste characteristics would be the high water content of the underwatered sludges and potential leaching problems, low bearing strength, and low solids volume. Within this context, the residual ash from wet oxidation and incineration processes would be the most suitable wastes and the undewatered biological and chemical sludges the least suitable.

To insure adequate safeguards of public health and environmental quality, regulatory institutions may impose operational constraints upon the sanitary landfill. The landfilling of wastewater residuals is primarily constrained by public health considerations, in particular, the hazardous nature of raw (i.e., undigested) wastewater treatment sludges. Such wastes contain large numbers of bacteria, viruses, and other pathogens. Digestion, dewatering, or incineration of wastewater sludges significantly reduces the possibility of infection from handling and disposition of these wastes by removing 30 to 100 percent of the original number of pathogens. General operational regulations may be based on sanitary landfill requirements recommended by the U. S. Environmental Protection Agency (Ref. VI-11).

Residual wastes are evaluated on their potential for groundwater contamination by consideration of the solubilities of their components and the resulting quality effects. The high organic content of unincinerated wastewater sludges would be expected to provide high concentrations of soluble organics and coliform bacteria to leachate waters. In addition, chelation and low pH may cause the heavy metals found in such sludges and surrounding refuse to leave the landfill in the leachate. Wet oxidation and incineration ashes are composed largely of low-solubility silicates but do contain some phosphates and other soluble salts.

Methane production is a function of organic matter content. As a result, wastewater sludges would be expected to contribute a significant amount to methane production within a sanitary landfill. Ashes and chemical sludges would contribute far less methane, owning to their low organic matter content.

In general, wet oxidation and incineration ash and dewatered chemical sludges appear to be best suited for sanitary landfill disposal. These wastes present the fewest operational and environmental problems. The biologic wastewater sludges, because of their high content of water and organic matter, present serious operational and environmental problems which would have to be compensated for in the design of the sanitary landfill.

Management Agency Control and Monitoring Program

Control

A management agency may control disposal of residual waste to sanitary landfills using a permit system, land use regulations, and, to a lesser degree, standards and disposal charges.

(1) General considerations of a permit system include:

- (a) accurate description of disposal site;
- (b) description of terrain alteration;
- (c) existing and future land use of the surrounding area;
- (d) projected use of the site after abandonment;
- (e) environmental impact survey;
- (f) existence of water resources and present or potential utilization of them;
- (g) chemical, physical, biological properties of the waste and possible pretreatment required;
- (h) monitoring requirements;
- (i) general geologic character of the disposal site and adjacent area including permeability and leaching properties of soil and subsurface strata;
- (j) highest probable annual groundwater table level and delineation of groundwater flow;
- (k) documentation of need for disposal to a sanitary landfill and discussion of disposal alternatives and reasons for rejection;
- (l) description of the process that produces the waste;
- (m) controls to mitigate erosion and surface runoff;
- (n) prevention of accidental fires at the landfill; and
- (o) inhabition of vector presence.

(2) Applicable standards controlling disposal of residual waste to a sanitary landfill concern pretreatment and subsurface and surface receiving waters which may be directly contaminated by leachates.

Standards concerning groundwater quality are usually broad, based on public health criteria. Surface water quality is usually regulated by well-defined effluent discharge or receiving water quality standards. Pretreatment standards that may be associated with permit requirements are usually well defined. Pretreatment standards are particularly stringent regarding moisture content (usually 10-15 percent solids) and presence of pathogens.

Additionally, local units of government may promulgate regulations controlling the presence of methane gas because it can constitute a safety hazard.

General considerations of standards include:

(a) quantity and rate of waste disposed at the site;

(b) toxicity of waste input and/or in receiving waters;

(c) number of pathogens in waste input and/or in receiving waters;

(d) bionutrients from waste in receiving waters; and

(e) compressibility and dewatering quality of waste input.

(3) General considerations of land use regulations concerning disposal of residual waste to sanitary landfills include:

(a) existing land use/zoning of disposal site (this is a significant control because sanitary landfills are usually close to urban areas and may occur near a well-developed section);

(b) because of the erosion potential, regulations may constrain the location of a sanitary landfill in the interests of soil conservation; and

(c) preclusion of future alternatives to land use at the disposal site.

Monitoring

To enforce regulations governing disposal of residual waste to sanitary landfills, general aspects of a monitoring program during operation and after abandonment include:

(1) delineation of the presence and directions of subsurface dispersion of waste constituents;

(2) surveillance of possible odorous gas produced at the site;

(3) detection of the presence and amount of methane gas produced at the site;

(4) measurement of the amount of subsidence after site abandonment (Regrading may be necessary to mitigate leaching. Regrading can prevent the formation of sag ponds that collect rain and can decrease possible soil erosion.);

(5) detection of leachates transported to surface water;

(6) delineation of the amount and severity of surface erosion and runoff to surface waters;

(7) seasonal variation in groundwater depth and direction of movement; and

(8) deposition of toxic substances in soil.

Costs of Sanitary Landfilling

Where wastewater sludge is landfilled, typical costs may increase due to more stringent environmental impact control, land costs, sludge dewatering, and transportation of the waste to the site. Burd (Ref. VI-12) provides the following costs for landfills (adjusted to June 1975): (1) operating costs \$0.95 to \$3.80 per ton and (2) capital costs of \$1.90 per ton. Figure VI-1 indicates a range of sanitary landfill capital and operation and maintenance costs (Ref. VI-13). Additional landfill costs presented as a function of transport distance are given in Figures VI-2, VI-3, and VI-4. These curves indicate the relative change in total cost of disposal as a function of distance. Land costs are not included, owing to the great difference in cost of land even in a particular geographic area. General land costs for the average value of one acre of farmland (Ref. VI-15), March 1, 1974, are presented below.

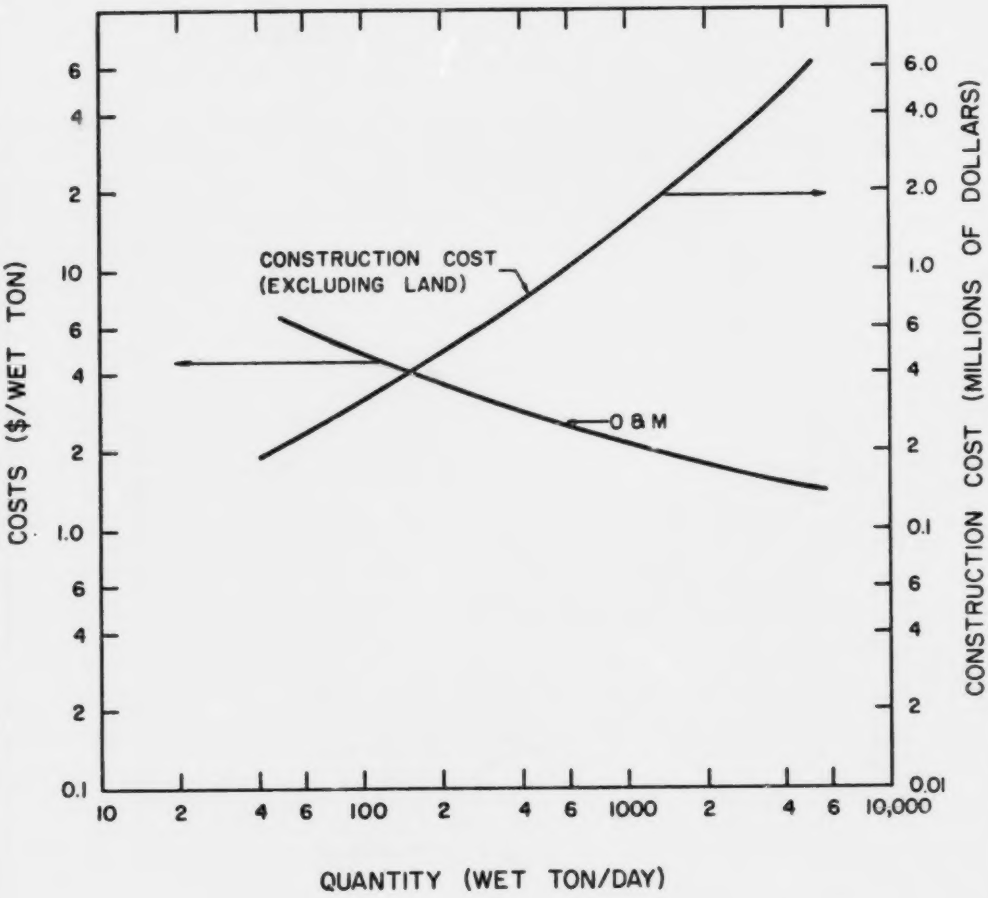
(1) Average acre of farmland in New Jersey is \$2,099.

(2) The states of Rhode Island, Connecticut, and Maryland are the only states (other than New Jersey) with the average cost of farmland greater than \$1,000 per acre.

(3) The average cost of farmland in the continental United States is \$310 per acre.

The cost of sanitary landfills is low compared to several other ultimate disposal methods. However, the increasingly higher price of land in conjunction with greater waste transportation cost makes other ultimate disposal methods worth examining closely in a given situation.

CAPITAL AND O/M COST FOR SANITARY LANDFILLS

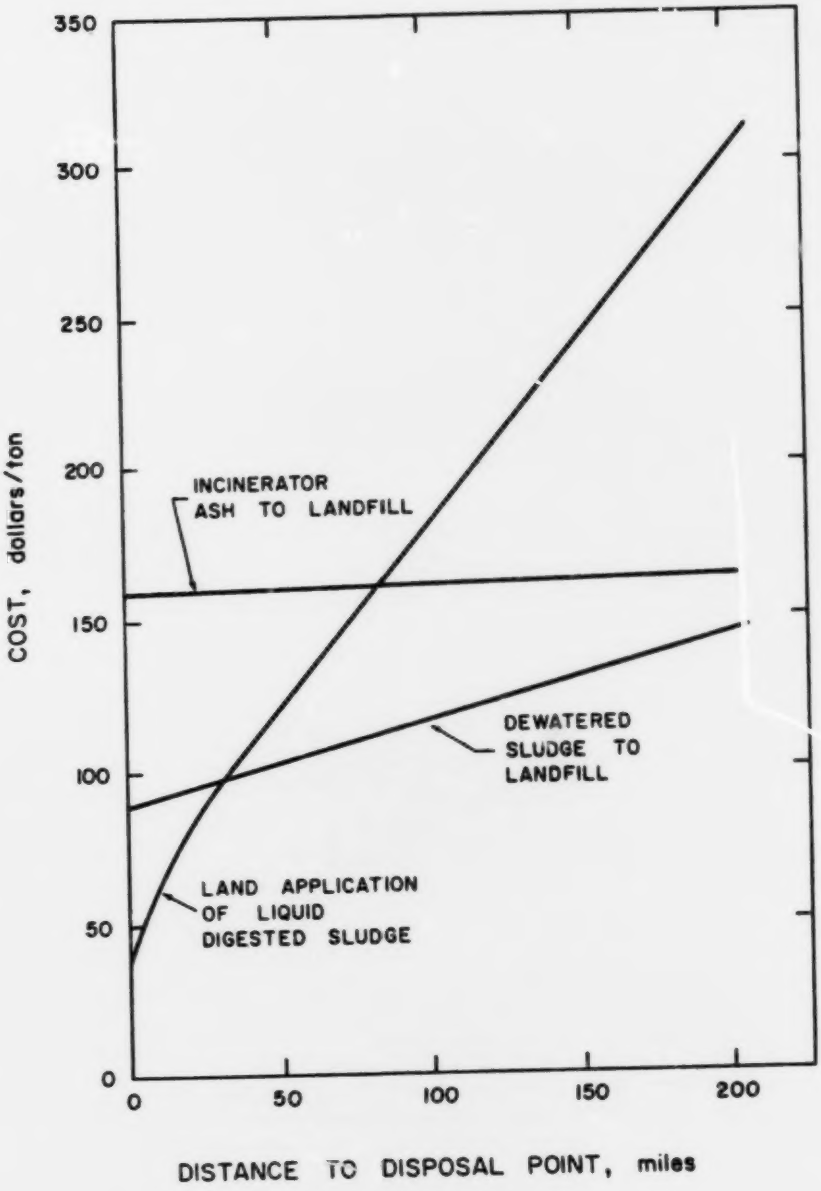


NOTES: 1. Minneapolis, June, 1975 ENR Construction Cost Index of 2200
2. Amortization of 7% for 20 Years
3. Labor Rate of $6.25 Per Hour
4. Quantity Assumes 6 Day Work Week
5. Wet Sludge Must Be Considered for Cost Per Ton
6. Source: U.S.P.H.S. and Stanley Consultants

SOURCE: Reference VI-13

FIGURE VI - 2

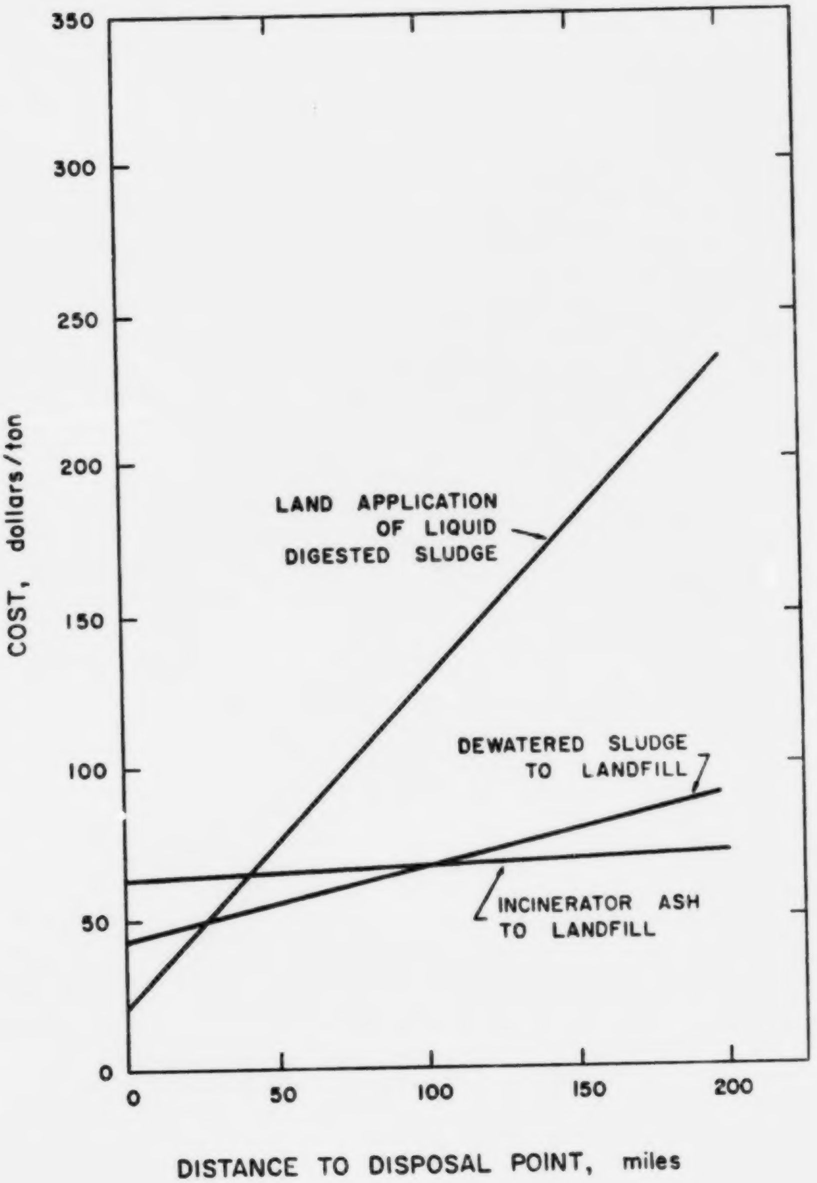
COMPARATIVE COST (1966) OF SLUDGE DISPOSAL
BY VARIOUS METHODS
FOR CITY OF 10,000 INHABITANTS



SOURCE: Reference VI - 14

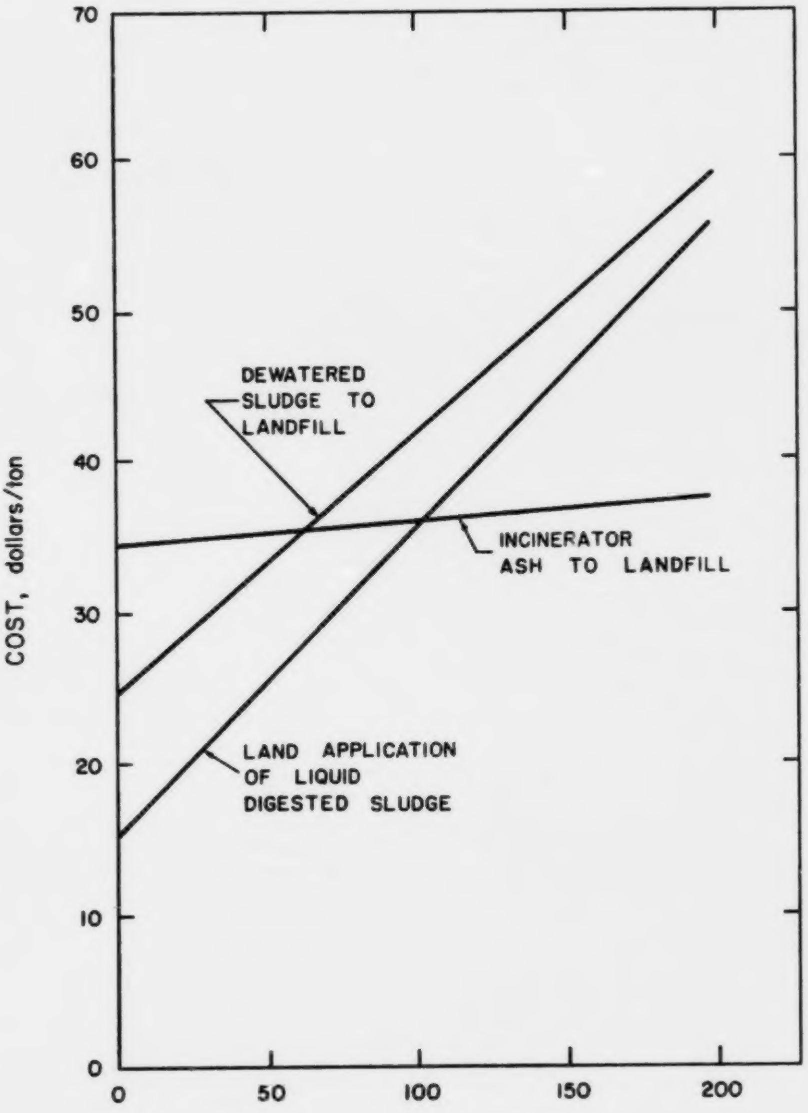
FIGURE VI-3

COMPARATIVE COST (1966) OF SLUDGE DISPOSAL BY VARIOUS METHODS FOR CITY OF 100,000 INHABITANTS



SOURCE: Reference VI - 14

COMPARATIVE COST (1966) OF SLUDGE DISPOSAL BY VARIOUS METHODS FOR CITY OF 1,000,000 INHABITANTS



SOURCE: Reference VI -14

WASTE DISPOSAL PONDS

Introduction

This section is concerned with ultimate disposal of water and wastewater treatment sludges to waste disposal ponds.

Lagoons are natural or artificial depressions in the ground which are used for processing wastewater and sludges in various ways including digestion of organic sludge, thickening, drying, storage, and ultimate disposal. Only the use of lagoons as a means for ultimate disposal of sludges will be examined in this section. Sludge lagoons are used for ultimate disposal because of their ability to concentrate and contain pollutants. Owing to their large surface areas, lagoons are susceptible to high evaporation which, along with settling, dewaters the sludge and reduces the volume. To a much less extent, drainage also dewaters the sludge, causing a more compact mass. Through these means of liquid-solid separation, solids remain in a local area where, by the design of the lagoon, little environmental impact is incurred. Due to minimal environmental effect and/or construction, operation and maintenance cost, sludge lagoons are a popular means of ultimate disposal. However, because of large land requirements and possible odor problems with organic sludges, use of lagoons is generally restricted to small wastewater treatment plants in rural areas of low population density where land is relatively inexpensive.

Few policy guidelines exist that specifically regulate the environmental impact of lagoons. Most regulations are at the state level and deal broadly with protection of groundwater resources, zoning laws, and protection of the public from nuisances such as the presence of flies and odors caused by lagoons.

Waste Characteristics

Sludge lagoons are suitable for ultimate disposal of both biological and chemical wastewater sludges. Lagoons will accept both lime and alum derived sludges, although alum sludge is not so easily compacted due to difficulty in dewatering. Discharging the sludge in smaller volumes by previous thickening or dewatering will enable a higher loading rate and/or longer use of the lagoon. In disposing lime sludge, up to 20-40 percent consolidation is possible and up to 50 percent if the supernatant is drained off (Ref. VI-16). Disposal of digested sludge to lagoons is generally more prevalent than undigested sludge because of reduced volume and lower volatile solids content, i.e., more stabilized. Smaller plants usually comprise the majority of facilities which dispose of undigested sludge in lagoons due to the small amount of sludge generated, more available land, and fewer people to be affected by odors. While wastewater treatment plants may dispose of their organic sludge, either digested or undigested, at varying percent solids, only in a few instances do plants also dump their residual grit into lagoons.

Toxic qualities of sludge are of particular concern in regard to transfer of toxic materials to ground water by percolation. Lagoon design usually allows for improvement of the waterholding characteristics of the bottom, or existing bottom soil porosity may be low so that leaching of toxic materials is insignificant. Lagoons may have plastic bottom liners (Ref. VI-17) to prevent drainage. If a high-percolation rate exists, the disposed sludge must have a low level of pathogens (sludge digestion is an effective disinfectant process) and especially low concentrations of nitrogen and heavy metals.

Operation Characteristics

Operation of wastewater treatment plant lagoons for ultimate disposal is basically concerned with influent sludge, settling of the sludge and supernatant flow if the lagoon is designed for supernatant discharge. Quality as well as quantity of influent sludge is regulated to prevent a rapid loss of disposal volume or an overflow of sludge or supernatant. Influent is pumped or gravity fed into the lagoon. Typical loading of raw solids is 96 kg/yr/cu m (160 lb/yr/cu yd) (Ref. VI-12). Inlet structures to achieve even distribution of sludge over the bottom may be fixed or portable. If more than one lagoon exists, the lagoons can be filled alternately. Sludge in the off-line lagoon can settle and the water associated with the sludge evaporate. While lagoons are best suited to warm and dry climates, lagoons are also operated in northern areas. Here, adequate provisions for extra disposal volume must be made to allow for lower evaporation and digestion rates. However, during the winter when the upper sludge layer freezes, the subsequent spring thawing helps dewater the sludge. The released water from the thawing process can then be drawn off to provide additional storage capacity in the pond. If the lagoon is operated with discharge or recycle of supernatant, then evaporation is not as significant to water removal from the lagoon. While supernatant discharge from some chemical treatment plant lagoons may be direct to natural receiving waters, supernatant from biological treatment plant lagoons should be recycled back through the wastewater treatment plant.

Siting/Environmental Considerations

Because of the containment character of lagoons, siting criteria are not so stringent as most other methods of ultimate disposal. Prevention of groundwater contamination by leachates is usually the most important criterion to be met. To minimize leaching of contaminants to ground water, a site should be selected with an impervious soil (i.e., high-clay content) and/or a low water table. Various design methods exist to prevent percolation through the bottom by reducing bottom permeability. These methods include soil compaction, and the use of soil cement, asphaltic composition, soil sealants, and various impermeable membranes (Ref. VI-18). Odor problems may be associated with operation of sludge lagoons. Such facilities should therefore be located in an area of low population density or at least be located downwind of local dwellings.

For a higher evaporation rate (for volume reduction), sludge lagoons are best suited to warm, dry areas. A warm climate aids sludge digestion and prevents typical spring odor problems which occur in colder areas as ice cover melts.

Resources that are utilized or may be impacted by disposal of residual waste to waste disposal ponds include the following:

(1) Water Quality - Disposal of residual waste via waste disposal ponds designed to drain the waste or by leakage will utilize the carrying capacity of available ground water. Possible impact on other resources includes the degradation of subsurface and surface water supplies by leachates, the degradation of surface water supplies by surface runoff (after site abandonment), and chronic deterioration of ecological conditions in receiving waters.

(2) Air Quality - Noxious and potentially hazardous gases such as methane may be exposed and dissipated to the atmosphere. Inhabitants of the surrounding area may then be subjected to nocuous odors from the disposal site.

(3) Land Quality - Possible impacts upon land-related resources include:

  (a) prevention of other surface land use by occupation of surface area by the disposal facility;

  (b) during construction, clearing the land necessary for surface facilities will probably cause immediate, temporary erosion; and

  (c) leaching through the bottom and sides of an unlined pond may deposit contaminants in the soil beneath and adjacent to the pond's perimeter.

(4) Aesthetics - Presence of the waste disposal ponds may disrupt the existing land use composition of the adjacent area.

(5) Public Health - Possible impact upon public health considerations includes:

  (a) the presence of toxic substances and pathogens in some residual wastes might damage public health when pathogens and/or toxic substances contaminate subsurface water supplies directly by leachates or surface water supplies by lateral groundwater transport of leachates to surface waters;

(b) agricultural cultivation, subsequent to abandonment of the disposal site, could produce crops that have incorporated toxic substances in edible portions of the plant; and

(c) entrapment of methane gas beneath structures built upon an abandoned site produces a potentially explosive situation.

Suitability of Disposal

In considering various ultimate disposal methods for wastewater treatment plant residual wastes, the general suitability of the waste to a particular disposal method can be readily ascertained by reviewing significant attributes of the method in regard to waste properties. In Table VI-3, a list of representative wastes is presented along with specific attributes of waste disposal ponds. Evaluation terms used in this table are based on both absolute and relative criteria.

While nearly any material can be disposed to a lagoon, in order to fully utilize the available volume the sludge must be fluid enough to pump and flow over the lagoon bottom. Those sludges which cannot flow in this manner are operationally constrained and the wastes listed in Table VI-3 have been evaluated accordingly.

As concerns regulatory institutions, the Federal government does not regulate disposal ponds. Most states have laws protecting groundwater quality sufficiently broad to cover leaching from ponds, but most do not have laws specifically regulating waste-disposal ponds. Due to the lack of specific regulations, Table VI-3 indicates the existence of no institutional constraints.

Where organic wastes are disposed by lagooning, objectionable odors may be generated as biological stabilization occurs. This is particularly true of relatively unoxidized organic waste. The representative sludges in Table VI-3 are evaluated with respect to their relative potential for causing odors based on their content of biodegradable matter.

Contamination of ground water underlying the disposal pond is possible due to the leaching of components in the waste. These components include pathogens such as bacteria and viruses, toxic materials such as heavy metals and pesticides, and generally high concentrations of dissolved solids. While conditions for appreciable leaching must be evaluated on a case-by-case basis, the relative potential for contamination of ground water by particular wastes is evaluated in Table VI-3.

Management Agency Control and Monitoring Program

Control

A management agency may control disposal of residual waste to waste disposal ponds using a permit system, land use regulation, and, to a smaller degree, standards.

TABLE VI-3

SUITABILITY OF VARIOUS MUNICIPAL WASTEWATER TREATMENT PLANT RESIDUAL WASTES FOR DISPOSAL BY WASTE DISPOSAL PONDS

Residual Waste	Operational Constraints	Institutional Constraints[1]	Odor	Potential Groundwater Contamination
Biological Treatment				
Primary Sludges				
Undigested	None	No	High	High
Thickened	None	No	High	High
Digested	None	No	Moderate	High
Activated Sludges				
Undigested	None	No	High	High
Thickened	None	No	High	High
Digested	None	No	Moderate	High
Sludge Cake	High	No	Moderate	High
Ash				
Wet Oxidation	High	No	Low	Low
Incineration	High	No	Low	Low
Chemical Treatment				
Alum Sludge				
Raw	None	No	Low	Moderate
Dewatered	None	No	Low	Moderate
Lime Sludge				
Raw	None	No	Low	Moderate
Dewatered	None	No	Low	Moderate

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[1] No institutional constraints are indicated owing to the lack of specific regulations.

(1) General considerations of a permit system include:

- (a) accurate definition of disposal site;
- (b) description of terrain alteration;
- (c) existing and future land use of the surrounding area;
- (d) projected use of the site after abandonment;
- (e) environmental impact survey;
- (f) existence of water resources and present or potential utilization of them;
- (g) chemical, physical, biological properties of the waste and possible pretreatment required;
- (h) monitoring requirements;
- (i) general geologic character of site and adjacent area including permeability and leaching properties of soil and subsurface strata;
- (j) highest probable annual groundwater table level and delineation of groundwater flow;
- (k) documentation of need for disposal to waste disposal ponds and discussion of disposal alternatives and reasons for rejection;
- (l) description of the process that produces the waste; and
- (m) controls for preventing surface runoff from entering the disposal pond(s).

(2) Applicable standards controlling disposal of residual waste by waste disposal ponds concern pretreatment and subsurface and surface receiving waters. Subsurface receiving waters may be directly contaminated by leachates. Standards concerning groundwater quality are usually broad and based on public health criteria. Surface receiving waters may be directly susceptible to pollution by erosion from the site after abandonment or indirectly by groundwater-carried leachates. Surface water quality is regulated by usually well-defined effluent discharge or receiving quality standards. Pretreatment standards that may be associated with permit requirements can be well defined.

General considerations of standards (pretreatment and receiving waters) include:

(a) quantity and rate of waste disposed at the site;

(b) toxicity of waste input and/or in receiving waters;

(c) potential for pathogens in waste input and/or in receiving waters;

(d) bionutrients from waste in receiving waters; and

(e) thermal character of waste input.

Additionally, local units of government may promulgate regulations controlling the presence of methane gas because it may constitute a safety hazard.

(3) General considerations of land use regulations concerning disposal of residual waste via waste disposal ponds include the existing land use/zoning of the disposal site (this is a significant control because disposal ponds are usually close to the wastewater treatment plant, probably in a well-developed area) and possible future alternatives to land use of the disposal site.

Monitoring

Based on a thorough preliminary (predesign) investigation, a program for monitoring the environmental impact of a sludge lagoon should focus on typical problem areas such as groundwater contamination, odors, quality of discharged supernatant, and maintenance of the inlet recycle pipelines. Groundwater downstream of the lagoon should be sampled for quality. Significant water properties to be analyzed are total dissolved solids, nitrogen chemical species, and heavy metals. Odors can be monitored by plant personnel reconnoitering the lagoon site. If supernatant is discharged to natural receiving waters, its quality should be periodically ascertained. Pipelines transporting sludge or recycled supernatant should be checked for leaks or breaks. Despite the presence of bottom sealers, leaks are possible and should be searched for. Such a leak may occur after the ponds are abandoned.

To enforce regulations governing disposal of residual waste by waste disposal ponds, general aspects of a monitoring program during operation and after abandonment include:

(1) delineating the presence and directions of subsurface dispersion of waste constituents;

(2) surveillance of odorous gas produced at the site;

(3) detecting the presence and amount of methane gas produced at the site;

(4) measuring the amount of subsidence after site abandonment (regrading may be necessary to mitigate leaching by preventing the formation of surface sag ponds or to decrease possible soil erosion);

(5) detecting the presence of leachates in surface waters;

(6) delineating the amount and severity of surface erosion and runoff to surface receiving waters;

(7) defining seasonal variation in groundwater depth and direction of movement; and

(8) evaluating deposition of toxic substances in soil.

Cost of Waste Disposal Ponds

Waste disposal ponds or lagoons are usually used for waste treatment, with eventual removal of accumulated bottom sludge to landfills or possible use as a soil conditioner (as in sludge recycling). When use of disposal ponds are a means of ultimate disposal, a new site must be selected and developed for use whenever the pond's capacity is exceeded. Thus, the total cost of the disposal pond is periodically incurred. An average lagoon capital and operating cost (updated to 1975) ranges from \$1.90 to \$6.65 per dry ton of solids handled (Ref. VI-12). These costs include short-distance sludge transport (generally by pipeline). Construction costs (updated to 1975) of lagoons can be estimated at an approximate cost of \$45,000 per acre (4.10 per ton per year) based on 20-year amortization at seven percent interest (Ref. VI-19).

SLUDGE RECYCLING

Introduction

Sludge recycling represents an attractive alternative to other sludge disposal methods in that it utilizes certain inherent characteristics of sludges for agricultural benefits. Unlike ocean dumping and landfilling, sludge recycling has the potential of offsetting capital and operating expenses with improved soil conditions and crop production. Sludge recycling is used in several communities in this country (Ref. VI-20, VI-21, and VI-22) and has been used in Europe for over a century (Ref. VI-23 and VI-24).

Sewage sludges contain macro plant nutrients (e.g., nitrogen, phosphorus, and potassium) at levels that are about one-fifth those found in commercial fertilizers. Biological sludges also contain necessary micro nutrients. Ranges in levels of these nutrients found in sludges from various areas of the country are shown in Table VI-4. The low nutrient levels found in sludges compared to inorganic fertilizers require higher and/or more applications of sludge in order to get results comparable to chemical

TABLE VI-4

MINERAL NUTRIENTS - PERCENT OF DRY SLUDGE SOLIDS

	Range
Total Nitrogen	3.5 - 6.4
Organic Nitrogen	2.0 - 4.5
Phosphorus	0.8 - 3.9
Potassium	0.2 - 0.7

Source: Ref. VI-25

fertilizers. While commercial fertilizers may contain a prescribed amount of nutrients, e.g., five percent nitrogen, ten percent phosphorus, and five percent potash, digested sludge (Ref. VI-26) contains an average 2.4 percent nitrogen, 2.1 percent phosphorus, and insignificant potash. However, the slow-release of the organic nitrogen in sludges is a desirable characteristic in that it provides a long-term nitrogen supply for crops and minimizes nitrate contamination of ground water. In addition to the nutrient value of sludges, their organic content aids in improving soil conditions by increasing the water-holding and buffering capacities of soils.

The long-term effects of sludge application on soils are not known conclusively at this time (Ref. VI-27). Heavy metals, pesticides, and polychlorinated biphenols are present in sludges and these are toxic to plants and microbial life at low concentrations in the soil solution. Fortunately, several soil processes make these toxic materials at least temporarily unavailable to the life cycles within the soil. However, the long-term impact of toxic compounds concentrating in the soil on the soil productivity are not conclusively known.

Some of the advantages offered by sludge recycling are given below.

(1) It requires little or no additional capital expense at the wastewater treatment site (except for storage during the cold season).

(2) It recognizes sludges as a resource and utilizes them as such. Consequently, costs incurred by this method can be offset to some degree by the utility of the sludge to agriculture. Direct costs incurred by sludge incineration or landfilling are not borne by the users.

(3) Certain sludges have sufficient quantities of nitrogen, potassium, and phosphorus to be of some value as fertilizers.

Sludge nutrients are released slowly, providing a long-term supply of plant nutrients.

(4) Certain sludges have excellent soil conditioning properties.

(5) The high water-content of sludges can serve as supplemental irrigation.

Some of the disadvantages of sludge recycling are given below.

(1) The relatively low available nutrient concentrations in sludges may require enrichment with chemical fertilizers.

(2) In some instances, a municipality would be competing with private enterprise for a market.

(3) There is no real tradition or precedent in American agriculture comparable to sludge recycling.

(4) Many sludges, including most chemical sludges, are unsuitable for recycling. For most municipalities, then, sludge recycling is only a partial solution to sludge disposal.

(5) There are many operational constraints, such as cold season storage of sludges, the daily weather variations, and relatively low application rates, which lead to extensive contingency planning.

(6) The long-term effects of sludge application to soil have not been adequately researched. Soil toxicity may occur after long periods of sludge application (Ref. VI-23).

(7) Possible contamination of groundwaters with heavy metals, toxicants (pesticides), and salts (TDS) may occur.

Considerable effort has been expended within the past few years by the Environmental Protection Agency, Army Corps of Engineers, and various universities and communities on pilot studies and demonstration projects directed toward the applicability of land treatment for wastewater effluent and sludges (Ref. VI-24). The emphasis on recycling and reclamation is in keeping with the current ecological perspective generated by deteriorating environmental quality, energy shortages, and inefficient use of resources. In addition to its research, the Federal government is prepared to fund much of the capital expense of a land treatment disposal system. The Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) authorizes a multi-billion dollar program to assist communities with 75 percent Federally funded grants for constructing sewage treatment facilities. Included in the facilities eligible for funding is the land required in land treatment disposal systems (Ref. VI-28).

Waste Characteristics

The characteristics of wastewater important to sludge recycling are those components and concentrations which improve or harm the soil-plant ecosystem. As discussed earlier, the nitrogen, phosphorus, potassium, and organic matter content of wastewater sludges are desirable components for soil conditioning and plant production.

The utility or toxicity of the various components of sludges is largely a function of those concentrations found in the sludge, those concentrations already in the soil, plant needs, and the physical-chemical-biological characteristics of the soil and not inherent to the component. For example, high application rates of sludge can lead to excessive quantities of available nitrogen and subsequent crop injury and possible pollution of the ground water with nitrates. Under the same high application rates, soils would be expected to have little problem immobilizing the heavy metals even under increased loading conditions. Moreover, plants require some heavy metals in order to complete their growth cycle.

In general, those sludge characteristics which are beneficial to sludge recycling are:

- nitrogen content
- phosphorus content
- potassium content
- organic matter content
- pH >6.0
- water and trace metal supplement

Most liquid and dewatered wastewater sludge contain these components at levels high enough for crop application. The risk components of wastewater sludges are the toxic metals and organics.

Operational Characteristics

Wastewater sludges can be applied to agricultural land in a liquid or dried condition. Liquid sludges are sprayed onto the land surface or injected into the soil using available farm equipment. Dried sludges can be used for both fertilizing and soil conditioning purposes. The sludge cake is dumped onto the land surface and is subsequently mixed with the soil by disking. If soil conditioning is the primary intent, the sludge cake (or compost) is usually pre-shredded befor application (Ref. VI-29). In general, dried sludges require more handling than liquid sludges and may require supplemental irrigation.

Application rates of sludges to cropland vary according to the nutrient requirements of the crop, existing soil characteristics (e.g., drainage, nutrient levels, heavy metal content, etc.), climate, and the characteristics of the sludge. In all cases, the application rate should be such that (1) crop production and quality are not decreased; (2) the soil does not build up excessive organic material or heavy metals; and (3) nutrients and excessive salts do not leak into surface or subsurface water supplies. A range of application rate values may be stated as a function of a particular physical parameter. However, because an application rate depends on several physical parameters inherent to a given geographical situation, rates specified in relation to a particular parameter, such as the following, should be viewed with caution. In applying liquid sludge on relatively nonpermeable soils, an upper limit of 46.8 cu m/day/ha (5,000 gal/day/acre) indicates, for applications not limited by heavy metals content of the sludge, a maximum application rate (Ref. VI-30, VI-31, and VI-32). To apply solid sludge, a maximum rate of 22.4 dry metric tons/yr/ha (10 dry tons/yr/acre) can be considered as a safe long-term rate (Ref. VI-33). In several cases a limit of 44.8 dry metric tons/ha (20 dry tons/acre) (Ref. VI-33, VI-34, and VI-35) may be used, or in other cases soil and sludge character may restrict the rate to only a few tons per year per acre (Ref. VI-36). Based on broad climatic criteria, a general application rate of 11-22 metric tons (12-24 short tons) of solids (dry weight) per 5000 sq m (6000 sq yd) per year has been found for humid regions (Ref. VI-37). An equation (Eqn. I) determining the maximum levels of sludge application for protection of cropland resources has been proposed by the U. S. Environmental Protection Agency. The equation serves as a guideline for soils that can be adjusted and held at a pH of 6.5 or greater for a period of at least two years after sludge application.

Equation I (Ref. VI-38):

$$\text{Total sludge (dry wt. tons/acre)} = \frac{32{,}600 \times \text{CEC}}{\text{ppm Zn} + 2\ (\text{ppm Cu}) + 4\ (\text{ppm Ni}) - 300}$$

where: CEC = cation exchange capacity of the unsludged soil in meq/100 g.

ppm = mg/kg dry wt of sludge.

This equation limits the heavy metal additions calculated as zinc equivalent to ten percent of the CEC. The zinc equivalent takes into account the greater plant toxicities of copper and nickel.

Sludge having a cadmium content greater than one percent of its zinc content should not be applied to cropland except under the conditions presented below.

(1) The land areas to receive such sludge are clearly identified in the grant application.

(2) There is an abatement program to reduce the quantities of cadmium in the sludge to an acceptable level.

(3) The project is reviewed by the U. S. Department of Agriculture and the Food and Drug Administration.

Siting/Environmental Considerations

The following is a list of site selection criteria for a sludge recycling program.

(1) Available Land - Sufficient producing or potentially productive agricultural land should exist within a reasonable distance of the sludge producer. A reasonable distance is defined by several factors including quantities of sludge produced and cost of transportation. The candidate sites should be composed of contiguous farmland in order to minimize monitoring and distribution costs.

(2) Public Acceptability - The populace that is expected to utilize the sludge must be made aware of all operational and environmental aspects of sludge recycling. Subsequently, there must be a good economic basis for their initial and continued acceptance of the method. Failing to provide for either of these needs could lead to abrupt termination of the disposal program.

(3) Climate - During the cold season, provisions must be made to store sludges until application is possible during the growing season. Depending on the lengths of these periods, storage costs and required acreage can be a problem. Precipitation and evapotranspiration during sludge application can present operational difficulties. For example, sludge recycling in arid regions will usually require supplemental irrigation. Humid regions will require reduced application rates and techniques which will reduce the potential for excessive leaching of nutrients and salts.

(4) Accessibility - Candidate sites should be accessible by dependable and economic transportation such as highways, pipeline, barge, or rail.

(5) Application Rates - Candidate sites should be able to utilize reasonable quantities of sludge in order to minimize acreage requirements and distribution costs. Application rates will depend upon climate, existing soil characteristics (e.g., pH, organic material content, nutrient availability, heavy metal content, etc.), types of crops grown, and sludge characteristics.

(6) Pollution Potential - Candidate sites should be amenable to long-term sludge application. Operational design of the system and

the natural character of the sites should minimize any deleterious impacts of sludges on soil quality, plant growth, surface runoff, and groundwater quality. This includes trapping and treating runoff from agricultural lands.

Sludge recycling principally impacts three segments of the agricultural ecosystem: (1) the soil; (2) the crops grown, both quantitatively and qualitatively; and (3) the drainage water quality. The constituents of sludge which have particular impact on these areas are the organic matter, nutrients, and heavy metal concentrations. The interactions of these sludge constituents with the land ecosystem create a complex system of interrelationships and subsequent effects of which only the most important will be discussed herein.

The organic matter in sludges is generally considered a valuable part of the sludge composition for sludge recycling. Organic matter provides a variety of beneficial effects to the soil system including: (1) increased permeability, (2) friability, (3) increased water holding capacity, (4) increased cation exchange capacity, and (6) adsorption of heavy metals. The degradational rate of organic matter, however, varies according to the type of sludge. Anaerobically digested sludges contain less-readily degradable organic solids than undigested or aerobically digested sludges. Consequently, anaerobically digested sludges cannot be applied at as high a rate as undigested or aerobically digested sludges without organic matter accumulating in the soil profile (Ref. VI-39). Excessive organic matter accumulation can adversely affect ion solubility and availability, plant growth, and drainage water quality (Ref. VI-39).

The nutrient concentrations of sludges, in particular those of nitrogen and phosphorus, are important to crop production. The organic nitrogen in sludges is released slowly and over a long period of time. This is a desirable feature of sludge decomposition as it provides a relatively constant long-term supply of nitrogen for plant assimilation and provides a maximum impact of soil denitrification processes which helps to eliminate excessive amounts of nitrogen in the soil (Ref. VI-40). However, heavy applications of sludge on the land can result in excessive available nitrogen which can result in crop damage and high nitrate concentrations in surface runoff and subsurface drainage.

The phosphorus in sludges is largely precipitated as aluminum (Al), iron (Fe), or calcium (Ca) phosphates. The phosphorus compounds are sufficiently insoluble so that very little phosphorus would be expected to leach into subsurface drainage. The capacity of soil to react with phosphates is very great owing to the large quantities of Fe, Al, and Ca present in most soils (Ref. VI-27 and VI-41). However, additions of large quantities of phosphorus to soils can result in over-fertilization with phosphorus, with subsequent crop damage and transport of phosphorus to drainage waters (Ref. VI-27).

Heavy metals, in particular Zn, Cu, Ni, and Cd, are added by sludge application in quantities in excess of natural levels found in most soils. These metals can, at relatively low available concentrations, render a soil wholly unproductive. Fortunately, heavy metals are largely unavailable for plant use and crop damage can be avoided with proper soil management. Study results have shown that most heavy metals are far less available at soil pH's above 6.5-7.0. Generally, a high organic matter content is desirable for control of heavy metal availability. The presence of phosphate and the cation exchange capacity of the soil also add to the immobility of the heavy metals.

Many of the observations and points made above have to be considered in both the short- and long-term operation of a sludge recycling program. Probably the greatest short-term problem would result from excessive application of sludge with subsequent break-through of nitrate and possibly phosphate into drainage waters. In the long-term, the greatest problem has to be the accumulation of heavy metals which could ultimately destroy the productivity of a soil.

Plants which are grown at the sludge recycling site should possess the characteristics of high nitrogen uptake, utility, and hardiness. Plants with these properties serving as a cover crop include alfalfa, corn, and general purpose forage grasses. Specific agricultural information for a given area may be obtained from the local Agricultural Extension Service.

Because of similarities in methodologies of sludge recycle and land reclamation, aspects of impacted resources will be discussed together here, although land reclamation will be discussed in depth in the following major section of this chapter. The main difference in methods is the primary goal of sludge utilization. Land reclamation is primarily concerned with sludge disposal, while land productivity and nutrient recycling are secondary objectives. The principle goal of sludge recycle is to dispose of sludge but coincidently to produce crops of economic value. The import of this is that in land reclamation the effects of high concentrations of toxic substances in the soil caused by large applications of sludge can be tolerated until plant growth is inhibited or wildlife feeding on the vegetation are affected. Sludge recycle by agriculture is vitally concerned with plant uptake of toxic substances because of the plants' eventual human consumption.

Resources that are used or may be impacted by disposal/utilization of residual waste (sludge) through sludge recycle and land reclamation include the following:

(1) Water Quality - Effluent from sludge recycle/land reclamation sites impact the following water-related resources:

   (a) using the carrying capacity of subsurface waters receiving leachates;

(b) using the carrying capacity of surface waters receiving surface runoff and groundwater-transported leachates;

(c) deterioration of subsurface and surface water supplies by leachates;

(d) degradation of surface water supplies by surface runoff;

(e) chronic deterioration of ecological conditions in receiving waters; and

(f) attenuation of erosion and surface runoff by growth of vegetation will improve surface water quality.

(2) Air Quality - Nocuous gas may be exposed and dissipated to the atmosphere after sludge is spread. Such odors may affect inhabitants of the surrounding area. When sludge is spread by an aerial distribution system such as a sprinkler system, aerosols, possibly containing pathogens, will be formed which may be transported by winds to contact local residents.

(3) Land Quality - Possible impact upon land-related resources includes:

(a) prevention of other surface land use by occupation of surface area by the disposal facility;

(b) improvement of soil quality by adding organic and inorganic nutrients;

(c) improvement of soil quality by conditioning soil, thus increasing humus content;

(d) clearing and regrading the land necessary for the landfill may allow immediate erosion to occur;

(e) erosion caused by runoff resulting from application of fluid sludge to land surface;

(f) land reclamation-mixing of sludge with surface materials (by disking) may cause erosion by exposing a new barren surface to weather elements, possible salt and toxic metal build-up;

(g) sludge recycle - physical manipulation of the soil for agricultural purposes (e.g., plowing) may cause erosion by exposing a new barren surface to weather elements;

(h) deposition of contaminants in soil by leaching beneath and adjacent to the facility's perimeter;

(i) land reclamation - prevention of erosion by presence of vegetation promulgated by sludge application;

(j) sludge recycle - increased agricultural production;

(k) sludge recycle - provide supplemental irrigation; and

(l) land reclamation - neutralization of acid soil by application of alkaline (lime) sludge.

(4) Aesthetics - Possible impact upon aesthetics includes:

(a) the presence of a sludge recycle facility may disrupt existing land use composition of the adjacent area;

(b) odors generated by the facility may affect inhabitants of the surrounding area;

(c) mechanical noise from the facility might annoy inhabitants of the surrounding area; and

(d) the presence of vegetation allowed by sludge application may be pleasing.

(5) Public Health - Possible impact upon public health considerations includes:

(a) agricultural cultivation for direct or indirect human consumption could produce crops that have incorporated toxic substances in edible portions of the plant;

(b) the presence of toxic substances and pathogens in some residual wastes might damage public health when pathogens and/or toxic substances contaminate subsurface water supplies or by lateral groundwater transport of leachates to surface waters;

(c) direct surface runoff may contaminate surface water with pathogens and/or toxic materials;

(d) vectors of pathogens (e.g., insects and rodents) may be attracted to the site which could allow dissemination of pathogens to populations in the surrounding area; and

(e) application of sludge by spraying will form aerosols possibly containing pathogens. The aerosols may be windblown from the site, contacting inhabitants of the adjacent area.

Specific Location Criteria

Important physical factors in predicting soil capacity for sludge assimilation include soil structure, porosity, grain-size distribution, and chemical characteristics. Because of the variety in soil types, some can readily assimilate large amounts of particular sludges and other types can assimilate only small amounts. While most soils are suitable for sludge application, soils which are most likely to be unsuitable are (Ref. VI-42): (1) extremely coarse-grained soils (coarse sands and gravel), (2) extremely fine-textured soils (such as montmorillonite clays), (3) very shallow soils (to water, bedrock, impermeable layers, or gravel), (4) wet, undrained soils, (5) frozen soils, and (6) solonetz and other sodium-saturated soils.

Surface slope is an important factor in consideration of sludge application rate because of water runoff or water ponding on the surface. While ponding occurs on flat terrain where soils are either of low permeability or are presaturated, water runoff generally increases with slope steepness. In protecting surface waters from runoff contamination, Table VI-5 indicates minimum distances of sludge application to water courses for sludge recycling in Ontario, Canada. The processed organic sludge mentioned in Table VI-5 has been stabilized by such means as anaerobic or aerobic digestion. To protect groundwater resources, a minimum depth of 1.22 meters (four feet) above high water tables or underlying rock is suggested (Ref. VI-36).

TABLE VI-5

LOCATION OF SLUDGE APPLICATION BOUNDARIES IN ONTARIO, CANADA

Maximum Sustained Slope	Minimum Distance to Watercourse	
	For processed organic waste application during May to November inclusive	For processed organic waste application during December to April inclusive
0 to 3%	200 feet*	600 feet
3 to 6%	400 feet	600 feet
6 to 9%	600 feet	No processed organic waste to be applied
greater than 9%	No processed organic waste to be applied unless special conditions exist	No processed organic waste to be applied

* one meter = 3.28 ft

Source: Ref. VI-43

Suitability of Disposal

The suitability of municipal residual wastes for sludge recycling depends primarily on three basic criteria: (1) operational considerations, (2) institutional restraints, and (3) the needs of the crop and soil. Table VI-6 compares a representative list of municipal residual wastes with these evaluative criteria. The qualifiers of low, moderate, and high are used for comparative purposes.

The primary operational consideration in sludge recycling is the ease of application. Liquid sludges can be transported and distributed by pipeline and applied using conventional irrigation equipment. Dried sludges require more handling and less efficient transportation methods.

Only a few states have regulations specific to wastewater or water treatment sludge disposal on land (Ref. VI-29). The principle concern with these wastes is that of public health and the degree of processing required to destroy pathogens found in the wastes. In general, digestion of the sludge is a minimum process requirement for use on any agricultural land. Specific laws and regulations do exist which prohibit the use of wastewater sludge on food crops that are eaten raw and on pasture land for dairy cattle (Ref. VI-29).

The value of municipal residual wastes to crop production is largely dependent on their nutrient (i.e., nitrogen, phosphorus, potassium, and trace element) content and to a much lesser extent, their utility as a soil conditioner. The soil conditioning value of the residual wastes is largely a function of the organic matter content, as discussed earlier, but can also include the beneficial effect of lime (i.e., calcium) on dispersed (i.e., sodium-rich) solids. All wastewater biologic sludges have some nutrient and/or soil conditioning utility and calcium chemical sludge may have some value as a soil conditioner. Sludge ash and alum sludges have little utility for recycling because of their low nutrient content and limited soil conditioning effects.

Management Agency Control and Monitoring Program

Control

A regulating agency may control disposal/utilization of sludge by sludge recycle (also land reclamation) using a permit system, standards, and land use regulations.

(1) General considerations of a permit system include:

(a) accurate description of proposed site;

(b) description of terrain alteration;

TABLE VI-6

SUITABILITY OF VARIOUS MUNICIPAL WASTEWATER TREATMENT PLANT RESIDUAL WASTES FOR SLUDGE RECYCLING/LAND RECLAMATION

Residual Wastes	Operational Constraints	Institutional Constraints	Nutrient Content	Soil Conditioning Benefits
Biological Treatment				
Primary Sludges				
Undigested	None	Yes	Moderate	High
Thickened	None	Yes	Moderate	High
Digested	None	Yes	Moderate	High
Activated Sludges				
Undigested	None	Yes	Moderate	High
Thickened	None	Yes	Moderate	High
Digested	None	Yes	Moderate	High
Sludge Cake	Moderate	Yes	Moderate	High
Ash				
Wet Oxidation	Moderate	No	Low	Low
Incineration	Moderate	No	Low	Low
Chemical Treatment				
Alum sludge				
Raw	None	No	Low	Low
Dewatered	Moderate	No	Low	Low
Lime sludge				
Raw	None	No	Low	Moderate
Dewatered	Moderate	No	Low	Moderate

(c) existing and future land use of the surrounding area;

(d) projected use of the site after abandonment;

(e) environmental impact survey;

(f) existence of water resources and present or potential use of them;

(g) chemical, physical, biological properties of the waste and possible pretreatment required;

(h) monitoring requirements (including levels of toxic substances in agricultural produce);

(i) general geologic character of the disposal site and adjacent area including permeability and leaching properties of soil and subsurface strata;

(j) highest probable annual groundwater table level and delineation of groundwater flow;

(k) documentation of need for disposal/utilization of sludge by sludge recycle or land reclamation and discussion of disposal alternatives and reasons for rejection;

(l) description of the process that produces the waste;

(m) controls to mitigate erosion and surface runoff;

(n) inhibition of vector presence;

(o) provision for storage, disposal, or utilization of sludge during periods when sludge cannot be acceptably spread on land, e.g., frozen ground, saturated soil;

(p) plan for dispension of agricultural produce; and

(q) attenuation of wind-(aerosol)transported pathogens.

(2) Applicable standards controlling disposal/utilization of sludge by sludge recycle/land reclamation concern pretreatment and subsurface and surface receiving waters which may be directly contaminated by leaches. Characteristics of regulating these receiving waters include:

(a) groundwater quality standards are usually broad, based on public health criteria; and

(b) surface water quality is usually regulated by well-defined effluent discharge and receiving water quality standards. Surface receiving waters may be directly susceptible to pollution by erosion from the site or indirectly by groundwater transport of leachates.

Pretreatment standards (that may be associated with permit requirements) are usually well defined. Pretreatment standards are particularly stringent regarding moisture content of input sludge.

Additional standards especially pertinent to sludge recycle methodology deal with control of toxic substances in agricultural produce for eventual human consumption and regulation of pathogens at the facility, e.g., pathogens carried in aerosols.

General considerations of standards (pretreatment and receiving environment) include:

(a) quantity and rate of waste disposed at the site;

(b) toxicity of waste input and/or in receiving waters;

(c) number of pathogens in waste input and/or in receiving waters;

(d) bionutrients from waste in receiving waters; and

(e) toxic substances in vegetation grown on site.

(3) General considerations of land use regulation concerning disposal/utilization of sludge by sludge recycle/land reclamation include:

(a) existing land use/zoning of sludge recycle site (this is a particularly significant consideration because land area requirements are usually high). This type of control is not generally applicable to land reclamation because of the land's existing poor condition being virtually of no beneficial use;

(b) because of erosion potential, regulations may constrain the location of a sludge recycle site in the interests of soil conservation;

(c) preclusion of future alternatives to land use at the site due to the large amount of committed area and build-up of toxic substances in soil; and

(d) use of land requiring the spreading of sludge may be constrained by public health regulations.

Monitoring

Monitoring the effects of sludges on the land ecosystem will be a necessary part of the management of the sludge recycling program. Because of the paucity of quantitative data relating to sludge application experiences and the always unique blend of soil, climate, crop, and sludge which will exist for every program, monitoring of the recycle program will serve several functions, the principal ones being research, operational characterization, and environmental protection. The monitoring program should include soil, plant, and groundwater analyses.

The objectives of soil analysis monitoring are to prevent toxic compounds in the soil from building up to the point where damage is done to crop production and drainage waters become contaminated. The biggest difficulty in using this technique is measuring the existing levels of a given ion in its plant available form. Currently, only a few techniques are known for some ions in some soil regions which measure the amount of available ion present (Ref. VI-44). Until research develops the necessary techniques, soil analyses should monitor such critical soil factors as pH, organic matter content, and total quantity and individual species of heavy metals and other critical ions.

The plant is the final arbitrator of the impact of sludge recycling on the soil. Such factors as nutrient mobility, nutrient solubility, placement and site of entry into the plant, and translocation within the plant are all indicated in plant composition (Ref. VI-44). Standard analytical methods for plant analyses currently exist which can be applied nationally. Plant analysis requires that the normal composition of the indicator plant be known along with the upper tolerance levels for the various toxic substances. Average composition levels of heavy metals for selected food crops are shown in Table VI-7 along with suggested tolerance levels. (It should be noted that these values are not necessarily endorsed by EPA.)

The effect of groundwater monitoring is to evaluate the operation of the sludge recycling program. Groundwater sampling should be done monthly over a period of several months prior to sludge application in order to provide adequate background data for comparative purposes. Monitoring wells should be located within the site, up-groundwater gradient from the site, and down-groundwater gradient from the site. Water samples should be collected within two to three weeks after sludge application and at the end of the growing season. Background water samples should be analyzed for the following parameters:

(1) Chloride

(2) Specific conductance

(3) pH

TABLE VI-7

THE PROBABLE AVAILABLE FORM, THE AVERAGE COMPOSITION RANGE FOR SELECTED AGRONOMIC CROPS, AND THE SUGGESTED TOLERANCE LEVEL OF HEAVY METALS IN AGRONOMIC CROPS WHEN USED FOR MONITORING PURPOSES

Heavy Metal	Probable Available Form	Common Average Composition Range* ppm	Suggested Tolerance Level** ppm
Cations			
Barium	Ba^{++}	10-100	200
Cadmium	Cd^{++}	0.05-0.20	3
Cobalt	Co^{++}	0.01-0.30	5
Copper	Cu^{++}	3-40	150
Iron	Fe^{++}	20-300	750
Manganese	Mn^{++}	15-150	300
Mercury	Hg^{++}	0.001-0.01	0.04
Lithium	Li^{++}	0.2-1.0	5
Nickel	Ni^{++}	0.1-1.0	3
Lead	Pb^{++}	0.1-5.0	10
Strontium	Sr^{++}	10-30	50
Zinc	Zn^{++}	15-150	300
Anions			
Arsenic	AsO_4^{--}	0.01-1.0	2
Boron	HBO_3^{--}	7-75	150
Chromium	CrO_4^{--}	0.1-0.5	2
Fluorine	F^{-}_{-}	1-5	10
Iodine	I	0.1-0.5	1
Molybdenum	MoO_4^{--}	0.2-1.0	3
Selenium	Seo_4^{--}	0.05-2.0	3
Vanadium	VO_3^{-}	0.1-1.0	2

* Average values for corn, soybeans, alfalfa, red clover, wheat, oats, barley, and grasses grown under normal soil conditions. Greenhouse, both soil and solution, values omitted.

* Values are for corn leaves at or opposite and below ear level at tassel stage, soybeans - the youngest mature leaves and petioles on the plant after first pod formation, legumes - upper stem currings in early flower stage, cereals - the whole plants at boot stage, and grasses - whole plants at early hay cutting stage.

Source: Ref. VI-44

(4) Total hardness

(5) Alkalinity

(6) (a) Ammonia - nitrogen

    (b) Nitrate - nitrogen

    (c) Nitrite - nitrogen

(7) Total phosphorus

(8) COD

(9) BOD

(10) Heavy metals found in sludges applied

Routine water samples taken during the operation of the sludge recycling program may be analyzed for only chlorides and specific conductance using them as indicators of groundwater quality change (Ref. VI-44). Full analysis would be required if these indicators deviated significantly from the background level.

To enforce regulations governing disposal/utilization of sludge by sludge recycle (also land reclamation, which is discussed in detail at a later point in this report), general aspects of a monitoring program during operation and after abandonment include:

(1) delineation of the presence and directions of subsurface dispersion of waste constituents;

(2) surveillance of odorous gas produced at the site;

(3) detection of leachates transported to surface water;

(4) delineation of the amount and severity of surface erosion and runoff to surface waters;

(5) seasonal variation in groundwater depth and direction of movement;

(6) deposition of toxic substances in soil;

(7) incorporation of toxic substances in vegetation grown on site; and

(8) pathogens carried off the site.

Costs of Sludge Recycling

Owing to the difference in location between the sludge source and application site, cost of sludge transport is an important factor, aside from the actual cost of application, in considering sludge recycling as a method of ultimate disposal. Figures VI-2, VI-3, and VI-4 show estimated comparative costs of sludge disposal by alternate means of cities of populations of 10,000; 100,000; and 1,000,000, respectively (Ref. VI-14). Table VI-8 indicates costs (updated to 1975) of sludge recycling at various sites in the United States. For undigested liquid sludge, costs (updated to 1975) vary between $8 and $57 per ton of dry solids with an average cost of about $19 per ton (Ref. VI-12). With the inclusion of capital and operating cost for anaerobic digestion the range increases to $15 to $95 per ton with an average of $29 per ton. The cost of land in a given area is, of course, an important constituent cost whether the land is bought out-right or leased. General land costs are presented in the section of this report concerning landfills. While the harvest of surface cover (crops) will to some degree offset application costs, a survey of community sludge disposal in northwestern Ohio (Ref. VI-36) indicated no return on crop sales, primarily due to emphasis on sludge disposal rather than gaining a resource return through crop sales.

TABLE VI-8

COSTS FOR LAND SPREADING DIGESTED SLUDGE

Location	Approximate Plant Size (mgd)	Cost ($/Ton)[a]
Chicago, Illinois	1300	75.98 = Current 44.23 = Ultimate[b]
San Diego, California	90	13.27
Piqua, Ohio	3.8	21.96 - 37.65
St. Marys, Pennsylvania	1.3	25.00

[a] Excludes digestion and costs are given per ton of digested solids updated to 1975.

[b] Ultimate costs include pipeline to be constructed. A principle variable is transportation cost.

Source: Ref. VI-45

LAND RECLAMATION

Introduction

The nutrient content and soil conditioning properties of many wastewater including chemical sludges can be utilized to build up marginally productive soils or reclaim nonproductive soils such as those derived from strip-mining operations. Approximately 1200 sq km (296,400 acres) of land in the United States have been used by coal strip-mining operations, with an additional 120 sq km (29,640 acres) being added annually to this total (Ref. VI-46). Strip mining generally degrades the water quality, aquatic environment, and riparian wildlife habitat by removing existing vegetation and topsoil, altering the surface drainage, and exposing fresh bedrock material which is unsuitable for plant growth (Ref. VI-46 and VI-47). Attempts to reclaim such sites by revegetation have been few and limited to Federal and State agencies, owing mostly to high capital costs (Ref. VI-46). As a result, large tracts of land exist which offer a potential for combined sludge disposal and land reclamation programs.

The objectives of a land reclamation program utilizing sludges differ from those of sludge recycling primarily in priority (Ref. VI-44). Whereas a sludge recycling program is limited by the usefulness of the sludge properties for crop production, land reclamation is concerned primarily with sludge disposal, with crop production and nutrient recycling being secondary objectives. In general, projected uses of reclaimed land are undefined but can be assumed to be some form of recreational, residential, commercial, and/or industrial use and not food production (Ref. VI-44). However, in the case of the Metropolitan Sanitary District of Greater Chicago, land reclamation of strip-mined areas is seen as a preliminary step in a long-term sludge recycling program which includes the production of food crops (Ref. VI-21).

Some of the advantages offered by land reclamation are given below.

(1) Large quantities of sludge can be disposed of per unit of land.

(2) A large variety of sludges or even mixtures of sludges can often be used.

(3) A land reclamation program can be operated year-round if the climate allows.

(4) At the end of sludge application, previously barren land will have more potential land uses.

(5) Land reclamation will improve surface water quality by controlling erosion and runoff, and upgrading existing soil characteristics.

Some of the disadvantages of land reclamation are given below.

(1) There are considerable site preparation costs.

(2) The operator-owner of the site becomes responsible for site runoff quality.

(3) The long-term effects of sludge application are still uncertain, especially in terms of heavy metal build-up and soil toxicity.

(4) Chemical sludges will require fertilizer enrichment in order to support vegetation.

Many of the operational and environmental considerations/mechanisms of sludge recycling are applicable to land reclamation utilizing sludges. The primary differences are related to the projected uses of the land being used. For land designated for uses other than food production, the effects of high concentrations of toxic metals in the soil, caused by large applications of sludge, can be tolerated until plant growth is impeded or wildlife feeding on the vegetation are affected (Ref. VI-44).

Waste Characteristics

The desirable characteristics of sludges for land reclamation are identical to those discussed under sludge recycling (see SLUDGE RECYCLING - Waste Characteristics of this chapter). However, in the case of strip-mined areas, the low pH of the soil is such a dominant factor prohibiting plant growth that improvements in soil pH are essential for plant growth. Coal strip-mine spoil contains pyrite (FeS) which oxidizes in the top, aerated layers to ferric hydroxide [$Fe(OH)_3$] and sulfuric acid (H_2SO_4). This causes the pH of the soil to be as low as two or three in many cases (Ref. VI-46 and VI-47). Most plants require soil pH's greater than those in order to survive. The addition of lime sludges generated by wastewater processes would aid in neutralizing the acid characteristics of the oxidized zone.

Operational Characteristics

Potential land reclamation sites will normally require extensive site preparation before disposal can begin. In the case of strip-mined areas, the land is highly irregular and must be leveled before use. In general, land reclamation programs require a closed system to prevent surface runoff from entering streams before sampling can be completed to assure that the runoff meets stream water quality standards (Ref. VI-48). This means that the construction of such structures as berms, dikes, and holding basins in addition to general regrading adds significantly to the cost of the program.

Digested liquid sludges appear to be an optimum sludge form for several reasons. Soil amelioration is best accomplished by thorough mixing of the sludge and spoil (or soil) material (Ref. VI-47). Mixing can be more easily and effectively achieved by the infiltration of the liquid sludge. The use of dewatered sludges would require extensive disking and supplemental irrigation in order to achieve similar results. Also, large volumes of liquid sludge can be applied using irrigation equipment and technology at a much lower operating cost than dewatered sludges. A digested sludge or stored sludge for 60-90 days would have far fewer pathogenic bacteria than an undigested sludge. This is an important factor when considering site runoff quality. A digested liquid sludge also has the advantage of not requiring expensive solids handling processes at the wastewater treatment plant.

Sludge application procedures are similar to those used in wastewater spray irrigation programs. Each site will be operated at an optimum application rate based largely on the infiltration capacity of the soil. Allowances will be made (in the form of intermittent operation) for soil drainage and normal precipitation, the primary objective being to minimize surface runoff. A reasonable range for loading rates would be from 4500 to 22,400 metric tons of dry solids per sq km per year (20 short tons to 100 short tons/acre/year) (Ref. VI-21 and VI-47). The Metropolitan Denver Sewage Disposal District No. 1 (Ref. VI-45) disposes 16-percent solids sludge cake on a bombing range at a rate less than or equal to 0.09 metric tons/sq km (25 dry tons per acre). This sludge is a conditioned mixture of raw primary sludge, anaerobically digested primary sludge, and aerobically digested excess activated sludge. Another specific case of land reclamation is in Illinois where the Metropolitan Sanitary District of Greater Chicago (Ref. VI-45) is applying digested sludge to strip mines at a decreasing rate from an initial 68 metric tons/acre/year (75 dry tons/acre/year) to 18 metric tons/acre/year (20 dry tons/acre/year) over a five-year period.

Periodic disking of the site prior to and during sludge application will be necessary to increase infiltration and deepen the zone of mixing. For strip-mine spoil, a mixing (plow) depth of 25 cm (10 in.) from the land surface is desirable in order to neutralize this most active (i.e., acid-producing) zone (Ref. VI-47). Seeding of the site should be done as soon as is reasonable after sludge application in order to reduce surface runoff and erosion.

Siting/Environmental Considerations

The following is a representative list of site selection criteria for a land reclamation program utilizing sludges.

(1) Available Land - Sufficient (i.e., enough acreage to handle long-term quantities of sludge) nonproductive land should exist within a reasonable distance of the sludge producer. A reasonable distance is defined by several factors including quantities of sludge produced and cost of transportation. The candidate sites should be composed of contiguous areas, preferably within a

minimum number of watersheds, in order to minimize land preparation, monitoring, and operating costs.

(2) Public Acceptability - The populace of the region should be made aware of all operational and environmental aspects of land reclamation utilizing sludges. Subsequently, there must be a favorable economic basis and reasonable compatibility with local land use planning objectives in order to insure continued acceptance of the program.

(3) Condition of Land - The candidate site topography cannot be so irregular that site preparation costs become excessive.

(4) Accessibility - Candidate sites should be accessible by dependable and economical transportation such as highways, pipelines, barge, or rail.

(5) Pollution Potential - Candidate sites should be amenable to long-term sludge application. The operational design of the system and the natural character of the sites should not only minimize any deleterious impacts of sludges, but improve soil quality, plant growth, surface runoff, and groundwater conditions.

Because land reclamation generally involves considerable recontouring of the land in order to control and minimize surface runoff, one of the initial impacts of the program will be the altering of the basin hydrology. In fact, most of the effects of the program, such as increasing soil productivity, and subsequently, vegetation cover, lead to changes in the basin hydrology. Increased vegetation cover along with recontouring reduces erosion and surface runoff. The additional water from the sludges results in greater groundwater recharge and subsequent increases in stream baseflows and watertable elevations. Evapotranspiration will be increased within the basin owing to increases in vegetative consumption and soil and water retention properties. Ultimately, the long-term impact of land reclamation, if managed properly, should result in a general improvement of the hydraulic and water quality characteristics of a basin.

Land reclamation, once it has passed the point where productive topsoil is produced, can be expected to have environmental impacts similar to those found in sludge recycling, which have been discussed earlier.

Suitability of Disposal

The suitability of municipal residual wastes for land reclamation follows much the same lines of reasoning discussed previously under sludge recycling (also see Table VI-6). In addition, the value of chemical sludges (in particular lime sludges) as a soil aid, especially in raising soil pH in strip-mine waste, is significantly increased.

Management Agency Control and Monitoring Program

The control program elements for land application of municipal residual wastes would be the same as those previously mentioned for sludge recycling.

The monitoring program for land reclamation should include soil, plant, groundwater, and surface water analyses. Except for surface water monitoring, which may be optional in sludge recycling programs, the monitoring provisions for land reclamation are identical to those for sludge recycling. Surface water monitoring for land reclamation can be expected to be a regulatory requirement because of the high rates of sludge application.

Surface water runoff will be a controlled feature of the land reclamation project and will not be released to open streams before it is analyzed and found to meet required stream standards. Parameters to be analyzed should include:

(1) Fecal coliforms

(2) pH

(3) Chlorides

(4) Alkalinity

(5) Specific conductance

(6) (a) Ammonia nitrogen

    (b) Nitrate-nitrogen

    (c) Nitrite-nitrogen

(7) Total phosphate

(8) COD

(9) Heavy metals found in applied sludges

(10) Turbidity

Costs of Land Reclamation

The following two land reclamation cases described in regard to sludge application rates serve as examples of land reclamation costs. In applying up to 0.09 metric ton/sq km (25 dry tons of sludge per acre), the Metropolitan Denver Sewage Disposal District No. 1 (Ref. VI-45) has incurred a cost (updated to 1975) of $56 to $69 per ton. The Metropolitan Sanitary

District of Greater Chicago (Ref. VI-45) has found the cost (updated to 1975) of preparing strip-mined land for sludge disposal to range from \$2300 to \$3500 per acre. Using barge transportation (1973) at \$36.81 per ton, the total cost of disposal is \$71.54 per ton of solids. Once pipeline transport is implemented, the total cost (1973) of sludge disposal is expected to be \$35.24 per ton of solids. These totals include sludge digestion at \$9.22/ton.

OCEAN DISPOSAL

Introduction

Ocean disposal of residual wastes is a form of ultimate disposal which exploits the ocean's large dilution capacity to alleviate possible detrimental effects of the waste upon sustained use of land-related resources. Thus, because of its size and mixing properties, the ocean may be, under properly engineered conditions, a convenient dumping place for various types of waste materials. In 1968, approximately 43 million metric tons (48 million short tons) of waste (U. S.) were discharged to the ocean. Included in this figure are 34 million metric tons (38 million short tons) of dredge spoil, 4.1 million metric tons (4.5 million short tons) of industrial wastes, 4.1 million metric tons (4.5 million short tons) of sewage sludges, and 0.5 million metric tons (0.5 million short tons) of construction and demolition debris (Ref. VI-49). In 1972, the amount of waste discharged into the oceans increased from 43 million metric tons (48 million short tons) to 47 million metric tons (52 million short tons).

Ocean quality is a relatively new concern in the development of environmental protection. Previously there existed few direct legal controls regulating ocean disposal of residual wastes. Legislative efforts were primarily aimed at controlling oil pollution and the effect of pollution from exploration and exploitation of natural resources. In 1970, the Council on Environmental Quality presented a report entitled "Ocean Dumping - A National Policy" (Ref. VI-50) which stated:

- Ocean dumping of undigested sewage sludge should be halted as soon as possible with no new sources allowed.
- Ocean dumping of digested or other stabilized sludge should be gradually stopped with no new sources allowed. Where substantial facilities and/or significant commitments exist, continued ocean dumping may be necessary until alternatives can be developed and implemented. Continued ocean dumping should be considered an interim measure.

In accordance with the report recommendations, Environmental Protection Agency guidelines were issued in 1971 which greatly inhibited use of the ocean as a site of ultimate disposal. During September 1972, the

President's Water Pollution Control Advisory Board issued a report, "Ocean Disposal Practices and Effects" (Ref. VI-51), which concludes that the presence of toxic materials, primarily the heavy metals, in municipal sewage can cause particular problems in the ultimate disposal of wastewater treatment sludge. There materials may have a harmful effect due to their possible entry into the marine food chain when ultimate disposal of sludge is to the ocean.

In October 1972, Congress passed the Marine Protection, Research, and Sanctuaries Act (Ocean Dumping Act). The purpose of this legislation is to regulate the carriage of substances from the United States for dumping into ocean waters. Substances are defined to include sewage sludge. Thus, in addition to the Water Pollution Control Act of 1972 (which covers all outfalls into marine waters as well as all types of discharges into the territorial sea) the Ocean Dumping Act covers all dumping in the U. S. ocean waters of the territorial sea and the contiguous zone. EPA guidelines promulgated by the Ocean Dumping Act (Ref. VI-52) were issued in October 1973 and impose stringent regulations and criteria upon ocean dumping. However, the EPA has published regulations (Ref. VI-53) describing procedures for application for, and issuance and denial of, permits for ocean dumping.

Waste Characteristics

Both wastewater and water treatment sludges can be disposed to the ocean. If the sludge can be pumped, then it may be discharged by barge or submerged outfall. The barge may be equipped with drop doors to dump thicker sludge. In general, flotable solids must be minimized due to the solids concentration at the surface. This is because only areal dispersion exists near the surface rather than three-dimensional dispersion which takes advantage of the ocean site volume.

The "Final Regulations and Criteria" for ocean dumping issued by EPA (Ref. VI-52) defines prohibited waste characteristics and materials requiring special care. Table VI-9 indicates a selection of prohibited wastes that apply to wastewater residual wastes from the EPA guidelines.

Operational Characteristics

Waste disposal to the sea is primarily by either a submerged outfall (pipeline) or by surface/near-surface dumping (barge). By ocean outfall, municipal wastewater sludge may be piped many miles to be discharged (usually) through a section of diffuser conduit several feet above the bottom. Typical operation is fairly simple, consisting of monitoring and maintenance of the pump, pipeline, and diffuser. Depending on operation of the solids removal process and resulting effluent concentration, active regulation of pump rate may be necessary. When sludge production is small enough to permit intermittent operation, the outfall may require flushing with fresh or reclaimed water after each discharge period to prevent sedimentation and possible clogging of the diffuser.

TABLE VI-9

A SELECTION OF PROHIBITED WASTES THAT APPLY TO WASTEWATER TREATMENT PLANT RESIDUAL WASTES FOR OCEAN DISPOSAL

Degree of Prohibition	Materials/Constituents
Complete	1. Materials insufficiently described in terms of chemical, and biological properties to evaluate in terms of environmental impact. 2. Inert materials which float or remain in suspension. 3. Biological agents capable of infesting, infecting or altering the normal populations of organisms, degrade uninfected areas, or introduce species not indigenous to an area.
Prohibited by exceeding defined amounts	1. Mercury: solid material - 0.75 mg/kg liquid material - 1.5 mg/kg 2. Cadmium: solid material - 0.6 mg/kg liquid material - 3.0 mg/kg 3. Oil and Grease: must be of consistency so that a visible surface sheen will not be produced in a quiesent water sample when added at a rate of one part water to 100 parts water.

Source: Ref. VI-52

Physical requirements of barging wastes to sea include shore facilities (collection systems, pumps, pipelines, storage tanks, and barge loading equipment), at least one barge (towed or self-propelled), and a dump site. Operation basically consists of first loading the barge by pump or gravity flow from storage tanks and then transporting the barge to the dumping area, usually by a specified time table. Once at the site, several runs are made within the area so all the waste is not released at one point. Sludge within the barge is discharged by pump or gravity flow usually into the wake to aid dispersion of the effluent. The cargo compartments may be flushed out depending on the sticky and gritty qualities of the sludge. During rough weather, the barge may not travel at all, thus requiring storage on shore, or waste may be transported in smaller quantities than normal.

Siting/Environmental Considerations

Prerequisite to a decision regarding the environmental feasibility of ocean disposal, a preliminary investigation of environmental conditions at potential discharge sites must be made.

Opportunities for affecting environmental quality by waste discharges include possible spills on shore and during transport as well as discharge at the site. With proper care in design, construction, operation, and maintenance, accidental spills can be minimized and are usually insignificant compared to the volume of waste discharged at the disposal area. Environmental effects of accidental discharges will probably be similar to the main discharge with primary differences in magnitude.

Despite the differences between ocean disposal by submerged outfall and surface dumping by barge (especially differences in depth and distance from shore of the discharge), several common siting criteria based on environmental effects exist and will be subsequently discussed. Since the concept of ocean disposal is environmentally founded on dilution, one of the most important criteria to be met is high dispersion characteristics at the site. Dispersion of waste constituents is primarily due to advective flows (ocean currents). Both current flow magnitude and direction must be considered in relation to location of ocean resources and discharge point. These resources include protection of the shoreline and bottom from waste deposition. Usually a sandy bottom condition is an indication of bottom scouring caused by water currents, and such a condition is generally sought. Other components of dispersion include eddy and molecular diffusion within the water column. A deterrent to vertical mixing that may occur during summer is the presence of a thermocline. By inhibiting vertical mixing, waste constituents will remain in greater concentration for longer periods of time.

Siting criteria more applicable to submerged outfalls are dependent on water depth and proximity to shore. By discharging waste near the bottom, rapid sedimentation of suspended solids will occur unless adequate dispersion exists. Ideally, the waste should have low vertical dispersion with great horizontal dispersion of suspended solids. Limited vertical mixing will enhance light attenuation which inhibits surface and near surface photosynthetic growth plus causing aesthetically displeasing murky water. Ocean swells in relatively shallow water can cause much vertical mixing, preventing sedimentation; therefore, discharge sites should be far offshore beyond the breaker zone. To prevent deep deposits of solids near the outfall which can adversely affect benthic organisms, the solids should be allowed to settle over as great an area as possible. The use of a diffuser at the outfall will aid in greater distribution longitudinally on the bottom and jet mixing from the diffuser ports will suspend the solids enough to allow lateral dispersion over a greater area. Evidence of potential solids transport from the site is given by the presence of high sand/low silt-clay composition of the bottom plus lower biomass and bionumber (Ref. VI-54). This implies a greater degree of scouring of sediments important for most effective dispersion and subsequent transport from the area.

The small amount of floatable solids in residual waste permitted for ocean disposal must be dispersed widely by water currents before appearing at the surface. In a similar manner, dissolved solids should be dispersed as greatly as possible. This conflicts with limited vertical mixing required of suspended solids which would cause greater waste concentration near the bottom. Depending on the waste, trade-offs must be made in siting conditions depending on the potential for adversely affecting ocean resources such as human health, welfare and aesthetics; the marine environment, ecological systems, or economic potentialities; or plankton, fish, shellfish, wildlife, shorelines, or beaches.

Siting criteria more applicable to surface discharge (from a barge) is less constrained than a submerged outfall primarily because of being discharged over a greater area and being further from shore. The dispersion conditions mentioned in connection with submerged outfalls is valid when dealing with barging; but, because of being dumped at the surface, subsequent settling deposition on the bottom is not as critical. However, because components of the waste will sink to a density equilibrium point providing a discrete cloud layer of potentially toxic water (Ref. VI-55), surface and mid-depth mixing becomes more important. By discharging to the surface, odor may also pose a problem if insufficient dispersion occurs. Surface discharge can generally disturb the marine ecosystem because surface and subsurface depths are particularly sensitive due to the presence of photosynthetic organisms which comprise the first element of the marine biological food chain. Toxins such as heavy metals may accumulate in higher organisms, e.g., fish and shellfish, by ingestion to the point of causing harmful physiological effects to these organisms.

Natural resources that are utilized or may be impacted by ocean disposal of residual waste include the following:

(1) Water Quality - Ocean disposal primarily makes use of the ocean's dilution capacity (a resource) to ameliorate nocuous components of the disposed waste. Possible impact on resources includes:

    (a) degradation of water supply (potential supply from desalination);

(b) chronic inhibition of particular biological elements in the marine ecosystem;

(c) disruption of marine fisheries (fish, shellfish, crustaceans);

(d) stimulation of particular biological elements in the marine ecosystem; and

(e) degradation of recreational value, e.g., primary contact such as swimming.

(2) Air Quality - Nocuous gases may be exposed and dissipated to the atmosphere upon discharge. Possible impact on resources includes the degradation of shoreline recreational and residential values.

(3) Land Quality - From the discharge point, waste components may be transported and deposited on the beach which could be detrimental to indigents of the littoral zones and create a public health problem to beach users. Solids from waste discharge may impede navigation by channel siltation.

(4) Aesthetics - Ocean disposal of residuals may detract from the aesthetic value of the sea and seashore by:

(a) causing waste floatables to exist at the surface;

(b) depositing waste components on the seashore; or

(c) generating nocuous odors.

(5) Public Health - The presence of toxic substances and pathogens in some residual wastes might infringe upon public health when:

(a) pathogens are in primary contact with humans, e.g., swimming;

(b) pathogens infect marine organisms used for food; or

(c) toxic substances (e.g., heavy metals) are present in marine organisms used as food.

Suitability of Disposal

Given a wastewater treatment plant residual waste to dispose of, the immediate question arises as to its amenability to disposal by a particular method. A list of representative wastes is presented in Table VI-10 along

TABLE VI-10

SUITABILITY OF VARIOUS MUNICIPAL WASTEWATER TREATMENT PLANT RESIDUAL WASTES FOR OCEAN DISPOSAL

Residual Waste	Operational Constraints	Institutional Constraints	Alteration of Benthos	Presence of Significant Toxics
Biological Treatment				
Primary Sludges				
Undigested	No	Yes	High	Yes
Thickened	No	Yes	High	Yes
Digested	No	Yes	Moderate	Yes
Activated Sludges				
Undigested	No	Yes	Moderate	Yes
Thickened	No	Yes	Moderate	Yes
Digested	No	Yes	Low	Yes
Sludge Cake	Yes	Yes	Moderate	Yes
Ash				
Wet Oxidation	Yes	Yes	Low	Low
Incineration	Yes	Yes	Low	Low
Chemical Treatment				
Alum Sludge				
Raw	No	Yes	Low	No
Dewatered	Yes	Yes	Moderate	No
Lime Sludge				
Raw	No	Yes	Low	No
Dewatered	Yes	Yes	Moderate	No

with specific attributes of ocean disposal. The waste evaluation term for each attribute category is based on both absolute and relative criteria.

The category of "operational constraints" in Table VI-10 is used to evaluate various wastes based on disposal alternatives allowed by the ease with which the sludge can be pumped to a subsurface depth. Waste is pumped to a point below the surface both from a barge (in addition to surface dumping) and from a submerged outfall. Of the listed wastes in the table, only those possessing a high percent of solids are constrained to non-pumped discharge.

All means of ocean disposal are constrained by Federal government regulations. These regulations are orientated toward waste constituents rather than general waste types (Ref. VI-52). In addition, the disposal site is also controlled by these regulations. Before an ocean discharge permit is granted, the federal regulations must at least be met before state regulations are considered.

The biological community (benthos) of the ocean floor may be affected by ocean dumping of wastes. These effects include (aside from specific toxics) physical deposition of solids on organisms and substrata causing abrasion plus lower available dissolved oxygen due to the BOD of the solids. Based on these two criteria, the listed wastes of Table VI-10 were evaluated in regard to relative alteration of the benthos.

While nearly any substance can be biologically toxic if present in great enough quantity, wastewater treatment plant residual wastes may contain materials which are toxic in relatively small concentrations. These materials include heavy metals, pesticides, and pathogens. In Table VI-10, representative wastes are comparatively evaluated concerning their content of significant toxics. Source controls, particularly for industrial inputs to municipal wastewater treatment systems, should be employed to alleviate the possible difficulties of using ocean disposal as a potential, viable alternative.

Management Agency Control and Monitoring Program

Control

Control that a management agency may impose on ocean disposal of residual waste can be exerted by means of a permit system, standards, and, to a smaller degree, land use regulation.

(1) General considerations of a permit system include:

  (a) specific designation of disposal site;

  (b) predisposal environmental impact survey;

  (c) quality standards of waste to be disposed;

(d) quantity of waste to be disposed;

(e) frequency of waste disposal;

(f) monitoring requirements;

(g) documentation of need for ocean disposal and delineation of disposal alternatives and reasons for rejection;

(h) conveyance of waste;

(i) description of disposal method;

(j) description of process that produces the waste; and

(k) contingency plan for barging when the ocean is too rough for shipping.

(2) General considerations of standards (pretreatment and receiving water) include:

(a) quantity of waste disposed in a specified area;

(b) toxicity of waste input and/or in receiving waters;

(c) number of pathogenic agents in waste input and/or in receiving water;

(d) inert materials that float or will remain in suspension contained in waste to be disposed;

(e) bionutrients of waste input and/or in receiving waters; and

(f) thermal character of waste input and/or in receiving waters.

(3) General considerations of land use control include:

(a) land use/zoning of shore facilities;

(b) land use/zoning of shoreline that may be affected; and

(c) zoning of affected ocean waters that may be allocated for other uses, e.g., fisheries.

Monitoring

An ocean disposal monitoring program should include operational feedback as well as independent environmental investigations. During operation of a submerged outfall, a record of sludge flow plus an indication of sludge quality should provide information on environmental impact given a thorough preliminary investigation before operation and during "normal" operation. Ocean disposal by surface discharge (barging) usually is operationally documented by the ship's log book. It may contain the following information: time of departure from shore, time of arrival at the site, location/time/direction of each dumping run, wind and water conditions during each run, and time of leaving site and arrival at port. Record of tank flushing may also be included in the log.

In general, the same environmental monitoring can be applied to both surface and submerged disposal. Given the characteristics of the waste, those constituents of relatively high concentration which are specified as "materials requiring special care" in EPA's regulations and criteria of ocean dumping are ones which should be quantitatively analyzed from site water samples. Water samples are taken from the "mixing zone" where area/depth is defined in the federal regulations. Periodic monitoring might typically include: (1) physical analysis-transparency, temperature, and odor; (2) chemical analyses-chlorides, dissolved oxygen, biochemical oxygen demand, organic nitrogen, nutrients, and total sulfides; (3) biological analyses-phytoplankton/zooplankton/coliform bacteria; and (4) benthic analyses-lithology, organism numbers and species. Sampling sites include particularly sensitive areas of protected resources, e.g., beach, shellfish, fish nurseries, etc.

To enforce ocean disposal regulations, general aspects of a monitoring program include:

(1) quality/quantity of waste through an ocean outfall;

(2) quality/quantity of waste and frequency of trips for barging (dumping);

(3) for ocean dumping, the ship's log should contain time of departure from shore, time of arrival at site, location/time/direction of each dumping run, wind and water conditions during each run, and time of leaving site and arrival at port;

(4) water and bottom quality at disposal site and in adjacent areas of ocean use, e.g., beaches and fisheries; and

(5) shoreline surveillance for deposited flotsam and existence of nocuous odors.

Costs of Ocean Disposal

The costs of ocean disposal can be presented by viewing ocean dumping (barging) separate from disposal by ocean outfalls. The range of barging costs (updated to 1975) along the Atlantic Coast is estimated (Ref. VI-56) to be $1.50 to $2.30 per ton. Burd (Ref. VI-12) presents several specific cases of sludge barging costs. New York City incurs a total cost (updated to 1975) of about $14.30 per ton of dry solids with an average round-trip distance of 25 miles. The cost of ocean barging from Philadelphia (updated to 1975) is $24.25 per ton of dry solids (wet sludge of 10-percent solids) and $32.60 per ton of dry solids (wet sludge of five-percent solids). Derr, et al (Ref. VI-53), estimate the total costs (updated to 1975) per dry ton for ocean barging to be slightly over $0.20/mile. Figure VI-5 indicates barging costs to a site 80 miles offshore using one, two, or three barges. The cost of an outfall is primarily dependent on the diameter and length of the pipeline. Figure VI-5 indicates estimated cost (1970) of outfalls ($/ton dry solids) for five- and eighty-mile discharge points. Burd (Ref. VI-12) states that operating cost (updated to 1975) at the Los Angeles Hyperion plant is expected to be $2.20 per ton of dry solids. Derr, et al (Ref. VI-53), estimate the total costs (updated to 1975) per dry ton for ocean outfalls to be $0.70/mile.

RESOURCE RECOVERY METHODS

Introduction

Wastewater treatment residual sludge is a valuable resource, generally unexploited in direct use or in producing a marketable product. Biological sludges may serve as a basic source of organic compounds and nutrient elements while sludges from physical-chemical processes may be treated to regenerate chemicals necessary to the wastewater or sludge treatment process. In general, resource recovery is an attempt to maximize resource utilization. Resource recovery has been relatively ignored due to lack of suitable markets for directly utilized sludge or manufactured end products, and the required high cost to convert sludge into a marketable product. A product of monetary value would reduce the cost for sludge management. When the cost for additional handling and processing of the sludge is less than the monetary value received for the product, then the total cost for sludge management will be reduced. The methods of resource recovery discussed in this section are:

(1) incineration;

(2) pyrolysis:

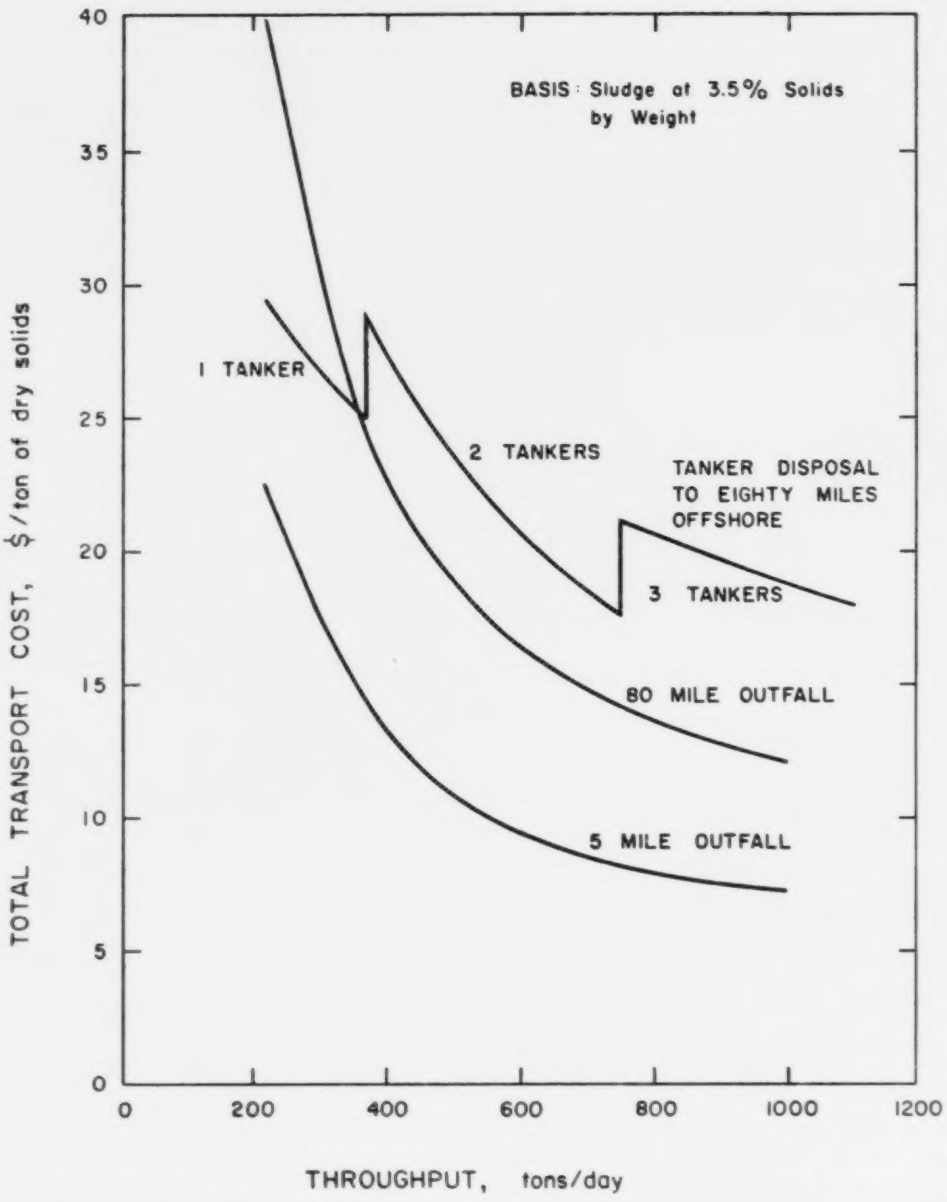
(3) lime recalcination;

(4) composting; and

(5) sludge recycle.

FIGURE VI - 5

COMPARATIVE ECONOMICS OF TRANSPORTING DIGESTED SLUDGE FOR OCEAN DISPOSAL



SOURCE: Reference VI - 57

Incineration

With adequate dewatering to approximately 30-percent solids, incineration is usually self-sustaining without the need for supplemental fuel. Table VI-11 is presented to indicate the general heat values of various sludges which may be incinerated. The advantage of incinerating undigested sludge can be noted in this table in that these sludges have a higher heat value than digested sludges. For activated or digested sludges with low heat values, supplemental fuels such as oil, natural gas, or excess digester gas are suitable, although it would be pointless to digest sludges prior to incineration; thus the two processes are not considered compatible. The multiple hearth furnace has been the most common type of equipment used for combustion of sludges because it is simple, durable, and it has the flexibility of burning a wide variety of materials even with a fluctuation in the feed rates. Fuel (sludge) burned in an incinerator emits heat; some is absorbed by the furnace and lost through radiation, a larger portion is lost with the stack gases, and a smaller portion is lost with the ash. The primary end products of combustion are considered to be water, sulfur dioxide, carbon dioxide, and inert ash (Ref. VI-12). The sulfur dioxide and particulates may be removed in the

TABLE VI-11

REPORTED SLUDGE HEAT VALUES

Description	Combustibles (%)	Ash (%)	Sludge Heat Value (Btu/lb)
Grease and Scum	88.5	11.5	16,750
Raw Sewage Solids	74.0	26.0	10,285
Fine Screenings	86.4	13.6	7,820
Digested Sewage Solids and Ground Garbage	49.6	50.4	8,020
Primary Sewage Sludge	---	---	8,990
Activated Sewage Sludge	---	---	6,540
Semi-Chemical Pulp Solids	---	---	5,812
Digested Primary Sludge	59.6	40.4	5,290
Grit	33.2	69.8	4,000
Pennsylvania Anthracite Coal (as a comparison to the above)			13,880

Source: Ref. VI-58

cyclonic jet scrubber and discharged with the ash as a slurry. In many incinerators the waste gases from combustion are heated to 1250 F (677 C) or higher to guard against odor nuisances. When land availability prevents the use of lagoons for ash slurry disposal, the inert ash is stored dry and periodically hauled away to convenient fill areas or possible by-product uses such as filter media aids or construction concrete aggregate.

Dewatering of sludge to about 25- to 30-percent solids prior to incineration in the multiple hearth furnace is usually required to prevent corrosion of the furnace materials and to aid in the combustion process.

Extensive air pollution control processes capable of 96- to 97-percent particulate removal efficiencies would be required to meet the national air pollution standards for municipal sludge incinerators. These standards are (1) no more than 0.65 g/kg dry sludge input (1.30 lb/ton dry sludge input) and (2) less than 20-percent opacity (Ref. VI-45).

Capacities of multiple hearth incinerators range from 200 to 8000 lb/hr of dry sludge with operating temperatures of 1700 F (Ref. VI-45).

A fluidized bed reactor incinerator is a relatively new process in the wastewater sludge treatment field. The sludge, usually after degritting, thickening, and dewatering, is fed into a bed of fluidized sand supported by upward-moving hot gases. The sludge is burned in the hot sand bed, and the ash is removed from the bed by the hot gases. The gases and ash are scrubbed and cooled in wet gas scrubbing equipment generally using wastewater treatment plant effluent as the scrubbing medium. The ash solids may then be separated in a hydrocyclone and the scrubbing liquid returned to the raw waste stream or recycled back to the scrubber. Advantages claimed for these incinerators are a high degree of sludge oxidation; relatively even operating temperatures; and relatively low operating costs because, with wastes of sufficient heat value, the combustion process is self-sustaining (Ref. VI-59). Loading rates of fluidized bed incinerators range from 220 to 5000 lb/hr of dry solids at 1400 to 1500 F.

Table VI-12 indicates the values obtained in the analyses of sewage sludge exhaust gases from multiple hearth and fluidized bed incinerators. Costs of incineration (both capital and O&M) are presented in Figures IV-1 and IV-2 in Chapter IV.

Heat Drying

Heat (flash) drying is the instantaneous removal of moisture from sludge solids by introducting them into a hot gas stream.

Wet sludge from a dewatering process is introduced into the cage mill with some previously dried sludge and hot gases from the 1300 F furnace. Drying is essentially completed in the cage mill; the sludge now approximately at 8- to 10-percent moisture. Dried sludge is separated from the

TABLE VI-12

SEWAGE SLUDGE INCINERATION EXHAUST GAS ANALYSES

Constituent	Average Constituent Concentration				
	Multiple Hearth			Fluidized Bed	
	South Lake Tahoe	Fairfax County	Monterey	Barstow	NW Bergen County
CO_2, % vol. of dry air	10.1	3.6	3.7	9.3	4.4
% Excess air at test point	51.7	272	307.2	49.6	---
SO_2, ppm	13.85	1.99	3.10	12.66	---
SO_2, lb/hr	0.1764	---	---	0.1514	---
NO_x, ppm	140.64	44.4-83.5	22.10	125.67	---
HCL, ppm	2.72	9.88	0.858	2.19	---
Filterable particulates					
gr/CF	0.0241	0.0132	0.0158	0.0527	---
gr/SCFD	0.0313	0.0176	0.020	0.0621	---
lb/hr	0.347	1.45	0.498	0.635	---
Total particulates					
gr/CF	0.0294	0.0180	0.0308	0.0617	---
gr/SCFD	0.0382	0.0242	0.040	0.0726	0.030
lb/hr	0.423	1.98	0.934	0.742	1.02

Note: Process Conditions:

Stack flow rate - SCFM (standard cubic feet per minute)	1273	9547	2793	1197	3650
Sludge feed lbs/hr D.S.	270.8	1222	---	462	650

Source: Ref. VI-59

spent gases in a cyclone and either sent to fertilizer storage or to the furnace for incineration.

Primary combustion air is preheated in the deodorized gas heat exchanger and introduced into the furnace as combustion of fuel such as gas, oil, coal, or wastewater sludge occurs. Ash accumulates in the furnace bottom and must be periodically removed either by sluicing to an ash lagoon, to a landfill, or to an ash utilization process such as vacuum or filter press operation.

Effluent gases passing through the furnace and combustion air preheater then pass through a dust collector and an induced draft fan to a discharge stack.

The use of this system for incineration alone has not proven attractive. Recovery of the dried sludge for sale as a fertilizer is currently practiced in Houston, Texas. Long-term contracts have produced revenues of approximately $21/ton of product. The dried product had a moisture content of five percent; ash, 35 percent; nitrogen, 5.3 percent; and available phosphoric acid, four percent (Ref. VI-45). As an incineration unit, the flash drying system has the disadvantages of complexity, potential for explosions, and potential for air pollution by fine particles.

Pyrolysis

Pyrolysis is the destructive distillation of refuse, sewage sludge, or other organic materials under pressure and heat in the absence of oxygen. Most of the combustion process is carried out within a closed reactor chamber, normally at temperatures lower than in incinerators.

The pyrolysis process has been used on a very limited basis and primarily on municipal refuse rather than sewage sludges. Where municipal refuse has been pyrolized, the products have been gases, pyroligneous acids and tars, and char. The gases consist mainly of hydrogen, methane, carbon monoxide, carbon dioxide, ethane, and ethylene. Tables VI-13 and VI-14 give the product yield and the approximate analysis of the pyrolysis char, respectively, of the pyrolysis of municipal refuse in San Diego, California (Ref. VI-13). The pyrolysis of digested sewage sludge yields the same products as those from the solid waste, although the char shows about 70 to 75 percent lower BTU content (Ref. VI-13).

There is an advantage to combining a pyrolysis plant with a sewage treatment facility to conserve energy and to help each of the individual processes. Methane from anaerobic digesters at the sewage plant could be used as a fuel in the pyrolysis system, while the waste heat from pyrolysis could, in turn, be used to aid sludge digestion. The char from the pyrolysis might be used as a filter aid in the sewage plant vacuum filter or centrifuge operations.

TABLE VI-13

PYROLYSIS PRODUCT YIELD

Temperature (°F)	Product Yield Percent by Weight			
	Gases	Pyroligneous Acids and Tars	Char	Mass Accounted for
900	12.33	61.08	24.71	98.12
1,200	18.64	59.18	21.80	99.62
1,500	23.69	59.67	17.24	100.59
1,700	24.36	58.70	17.67	100.73

Source: Ref. VI-13

TABLE VI-14

PROXIMATE ANALYSIS OF PYROLYSIS CHAR

	Proximate Analysis of Pyrolysis Char at Indicated Temperature (°F)			
	900	1200	1500	1700
Volatile matter, %	21.81	15.05	8.13	8.30
Fixed carbon, %	70.48	70.67	79.05	77.23
Ash, %	7.71	14.28	12.82	14.47
Btu per lb.	12,120	12,280	11,540	11,400

Source: Ref. VI-13

A sludge pyrolysis process is scheduled for operation by 1977 in Minneapolis/St. Paul, Minnesota (Ref. VI-60). The system will take 15 to 40 percent of the dewatered sludge from the secondary wastewater treatment system to the pyrolysis unit for disposal. The sludge pyrolysis unit will use municipal refuse as the source of fuel for the processing of sludge and production of both fuel char and process char which can be used in augmenting the overall treatment and sludge disposal system.

The major features of the system were described as follows (Ref. VI-60):

> "A mixture of sludge and refuse is dried to remove most of the moisture and then fed into a rotary kiln. The kiln is externally heated by a furnace that burns the gaseous and liquid fuels derived from the pyrolysis off-gasses. The mixed material is thoroughly agitated and exposed to temperatures of 1250 F for 30 to 60 minutes, driving off volatiles and leaving a char material consisting mainly of carbon and ash.
>
> "The kiln off-gasses are collected and processed in a gas cleaning system that condenses out the tar and oils. The remaining gas is suitable for fuel gas, having a heat value of approximately 450 BTU per standard cubic foot. The product gas is stored in a gas holder and continuously delivered to the kiln furnaces as needed to support the mixture drying and pyrolysis operation. Excess gas is used to supplement other thermal needs.
>
> "The tar and oils condensed from the pyrolysis off-gas stream are stored in tanks, then blended to produce fuel oil, and finally delivered to oil burning devices within the plant.
>
> "The char produced by the pyrolysis kiln is cooled and delivered to a sizing and de-ashing processing stage that produces three fractions: Char suitable for processing into activated carbon; fuel-grade high ash char for delivery to the primary sludge incinerators to reduce the need for purchased fuels; and a residue of inert ash, containing some fixed carbon, to be disposed of in a landfill."

The various fuels produced in the operation will be incorporated into the overall system thus reducing the need for purchased fuel oil and natural gas. Cellulose products, ferrous metals, glass, and aluminum will be sorted from the refuse and sold to provide an additional source of revenue. Refuse in excess of the system's needs will be baled and taken to a sanitary landfill where it will occupy less than one-half the space per ton required in conventional sanitary landfill practice.

Pyrolysis, being a new concept applicable to wastewater treatment sludges, has not had a separate, detailed breakdown of costs. Table VI-15 does, however, indicate the costs estimates for a complete sludge treatment system which includes pyrolysis. It was noted that from 15 to 40 percent of the dewatered sludge from the secondary subsystem (approximately 63,000 to 168,000 pounds of dry solids per day) would go to the pyrolysis unit (Ref. VI-60).

Lime Recalcination

Lime is often used in wastewater treatment as a coagulant for phosphorus removal. It can be applied either as a tertiary step or ahead of the primary clarifiers in either a biological or physical-chemical wastewater treatment plant.

The process of recalcining involves heating the dewatered sludge containing calcium driving off the water and carbon dioxide and leaving the calcium oxide (quicklime). When coagulating raw wastewaters, the inert solid fraction can be removed before recalcination by centrifugation. This inert solid removal must occur to prevent solids buildup within the wastewater treatment process.

The advanced wastewater treatment plant at South Lake Tahoe, Nevada, has used lime recalcination to recover lime for reuse since April 1968. Over this period makeup lime has accounted for 28 percent of the calcium oxide used (Ref. VI-45). The advanced wastewater treatment plant planned for Cleveland, Ohio, also anticipated the use of lime recovery by recalcination in a multiple-hearth incinerator. It is anticipated that, from a total daily sludge solids production of 196,900 pounds for the average daily flow of 50 MGD, approximately 62,400 pounds per day of lime can be recovered (Ref. VI-61).

Table VI-16 indicates the costs for recalcination of lime sludge (Ref. VI-62). The total capital cost includes thickening, centrifugation (dewatering) and the furnace. Make-up lime was computed using the assumption that 350 mg/l of lime (CaO) is required and that 1.2 ton/day/mgd of lime is recovered through recalcination.

Composting

Composting is the biochemical decomposition of organic matter in municipal, agricultural, and industrial wastes resulting in a generally sanitary, nuisance-free, humus-like material. The main value of this material is due to its high organic content which can act as a soil conditioner providing poor soils with better tilling properties, water-holding capacity, and improved nutrient-holding capacity (Ref. VI-63). However, compost is not a complete fertilizer unless it is supplemented by additional nutrients. A good compost could possess up to two-percent nitrogen, one-percent phosphoric acid, and many trace elements (Ref. VI-12).

TABLE VI-15

SLUDGE TREATMENT INCLUDING PYROLYSIS

ESTIMATED CAPITAL AND ANNUAL COSTS

	Capital Costs			Annual Cost		
	Estimated Construction Cost (000)	Engineering Legal and Administration (000)	Total Capital Costs (000)	Capital Recovery Costs (000)	Operating and Maintenance (000)	Total Annual Costs (000)
Primary Sludge Subsystem						
Sludge storage[1]	(Existing)	---	---	---	$ 25	$ 25
Sludge conditioning and dewatering[2]	(Existing)	---	----	---	1,045	1,045
Sludge incineration[3]	(Existing)	---	---	---	537	537
Secondary Sludge Subsystem						
Sludge thickening[4]	$13,277	$1,328	$14,60	$1,379	422	1,801
Sludge storage	4,900	490	5,390	509	105	614
Sludge conditioning (Thermal)[5]	17,861	1,786	19,647	1,855	421	2,276
Waste heat recovery[6]	6,444	644	7,088	669	405	1,074
Sludge dewatering	4,933	493	5,426	512	612	1,124
Sludge drying	14,008	1,401	15,409	1,455	580	2,035
Sludge pyrolysis	14,500	1,450	15,950	1,506	2,042	3,548
Totals	$75,923	$7,592	$83,515	$7,885	$6,195	$14,080
Total annual revenues[7]						1,602
Net total annual costs						$12,478

[1] Existing concentration and holding tanks.

[2] Existing chemical conditioning and vacuum filters, F & I # & F & I #2.

[3] Existing multiple hearth incinerators F & I #2. O & M costs do not include auxiliary fuel costs which are covered under costs of waste heat recovery.

[4] First cost covers new flotation thickeners. O & M costs include existing gravity thickeners and new flotation thickeners.

[5] O & M costs for thermal sludge conditioning do not include steam costs which are covered under costs of waste heat recovery.

[6] O & M costs cover production of steam for thermal sludge conditioning requirements together with normal plant heating loads.

[7] Annual revenues include the following:

(a) Sale of dried (20% of moisture) sludge not burned for heat recovery = $ 420,000/year
(b) Pyrolysis system-refuse dump charge = 468,000/year
(c) Materials recovered from refuse to pyrolysis system = 714,000/year

Total Revenues = $1,602,000/year

Source: Ref. VI-40

TABLE VI-16

RECALCINATION OF LIME SLUDGE FROM LIME CLARIFICATION PROCESS

Item	Capacity			
	1 mgd	10 mgd	100 mgd	309 mgd
Total Capital Cost, dollars	200,000	640,000	2,000,000	3,550,000
Process Cost, cents/1000 gallons				
1. Amortization, 7% and 20 yr.	5.18	1.65	.52	.092
2. Operating Labor	2.5	.595	.138	.066
3. Maintenance Labor	.190	.190	.190	.190
4. Supervision and Payroll Overhead*	.806	.236	.110	.077
5. Maintenance Materials**	.063	.063	.063	.063
6. Electrical Power	.100	.100	.100	.100
7. Fuel	1.33	.824	.47	.353
8. Make-up Lime, $18.50/ton	.48	.48	.48	.48
Total Recalcination Cost, cents/1000 gallons	10.65	4.14	2.07	1.43
Recalcination Plant Capacity, tons/day	1.2	12.0	120.0	371.0
Recalcination Cost, dollars/ton	88.75	34.50	17.25	11.91

*Taken as 30% of operating and maintenance labor

**Taken as 1/3 of maintenance labor (maintenance cost = 75% labor + 25% materials)

Source: Ref. VI-62

Degradation is accomplished by windrowing the waste with periodic mixing or by aeration in a mechanical device (Ref. VI-45). From the EPA manual on sludge treatment and disposal (Ref. VI-45), the following sequential steps are usually involved in composting:

(1) Preparation - Sludge may be and is often blended with a bulking material, e.g., sawdust or wood chips. The final moisture content should exist between 45 and 65 percent by weight. Normal sludge to bulking material ratios are usually about 0.50 to 1.00 by weight.

(2) Digestion - During decomposition, air must be supplied to the compost by agitation or forced draft. Wastes usually reach a temperature of 140 F to 160 F. These temperatures kill many pathogens. Digestion generally requires about six weeks for windrows and several days for mechanical aeration methods. Digestion is considered complete when the carbon-nitrogen ratio of the compost reaches 20 to 1.

(3) Curing - The decomposition rate is slowed until digestion is brought to completion usually in two more weeks for a windrow system and in one to two weeks for mechanical methods.

(4) Finishing - Screening to remove large objects may be necessary.

In marketing compost, a company in San Francisco (as of 1968 - Ref. VI-12) has been selling a composted mixture of digested sewage sludge, coffee grounds, and rice hulls. However, in general composting plants are not profitable ventures owing to lack of a market for compost. Of the 18 plants built between 1951 and 1969 in the United States, only a few are currently operated and many of these are operated only occasionally (Ref. VI-12).

The cost of composting varies widely and ranges from (October 1974) $2 to $20/ton (Ref. VI-45). The sale of compost usually brings a revenue of $1.50 to $3.50/ton of material fed. A pilot composting plant (Ref. VI-64) in Maryland estimates costs (June 1974) of $7.31 per wet ton or $30 per dry ton for processing 200 wet tons per day (20 percent solids, digested sludge).

Sludge Recycle/Marketing

In a previous section of this chapter, sludge recycle was discussed in detail concerning direct application of sludge by public or semi-public institutions to farmland. This section will briefly discuss the retail sale of processed sewage sludge (amenable to sale by private entrepreneurs) for agricultural purposes.

In general, the sale of processed (usually dried) sludge suffers the same problem of non-marketability that afflicts the other resource recovery methods previously discussed. While processed sludge is a good fertilizer and soil conditioner, commercial fertilizers have a higher nutrient content for a given price. Thus, the commercial fertilizer will usually be preferred.

In the Washington, D. C., area (Ref. VI-65) a private company is planning to sell dried sewage sludge as a 6-4-10 (percent nitrogen, phosphoric acid, potash) fertilizer at a price (June 1974) of about five dollars per 50 lb bag. The profitability of such a venture is unknown, especially since a commercial fertilizer provides a much higher nutrient content for that price.

The City of Winston-Salem (Ref. VI-66) tried to market air-dried sludge sold under the name of "Grogonite." Grogonite contained approximately three percent nitrogen, three percent phosphoric acid, and less than two-tenths of one percent potash. This product would sell (1973) for about $18 to $20 per ton. Marketing of Grogonite was not a profitable venture due to inhibiting marketing laws and institutional hesitancy in becoming involved in marketing and selling and promoting the product. The City decided to stop trying to sell Grogonite but instead to sell their air-dried sludge to Organics, Inc. of Rhode Island (State) which makes and sells a commercial fertilizer component named Organiform-SS. Organics, Inc. will return to the city a net payment (1973) of $5 per ton.

Milwaukee and Chicago (Ref. VI-12) have marketed heat-dried activated sludge at a price (updated to 1975) generally between $23 and $34 per ton (not a profit, however). The City of Milwaukee sells their sludge under the trade name of Milorganite which contains six-percent nitrogen, four-percent phosphate, 0.4-percent potash, and like most organic sludges, numerous agriculturally beneficial trace elements (Ref. VI-12).

In summary dried organic sludge can be used for agricultural purposes thus serving as a form of resource recovery and coincidently disposing of a residual waste. However, due to the relatively high cost of processing (for the resulting nutrient value as a fertilizer) compared to commercial fertilizers, the sludge cannot be profitably marketed.

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CHAPTER VI

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CHAPTER VII

EVALUATION PROCEDURES, CRITERIA, AND CONSTRAINTS

INTRODUCTION

Within the confines of the geographic areas covered under regional plans prepared for Section 208, an administrating state or regional planning agency may have several residual waste management options to consider. An optimum management option is a system that will reliably meet the criteria set for the system in an economic and resourceful manner. The costs incurred by and benefits derived from each alternative must be evaluated in an equitable and systematic fashion as a prerequisite to rational decision-making. Facilities costs can be readily calculated because society places an identifiable value on the labor and materials necessary for their operation and construction. However, difficulties arise when less tangible environmental aspects of the options are to be evaluated. The value of clean waters, fresh air free from odors, absence of noise, and beautiful, productive lands in a community are subject to different interpretations by individuals varying in their points of view.

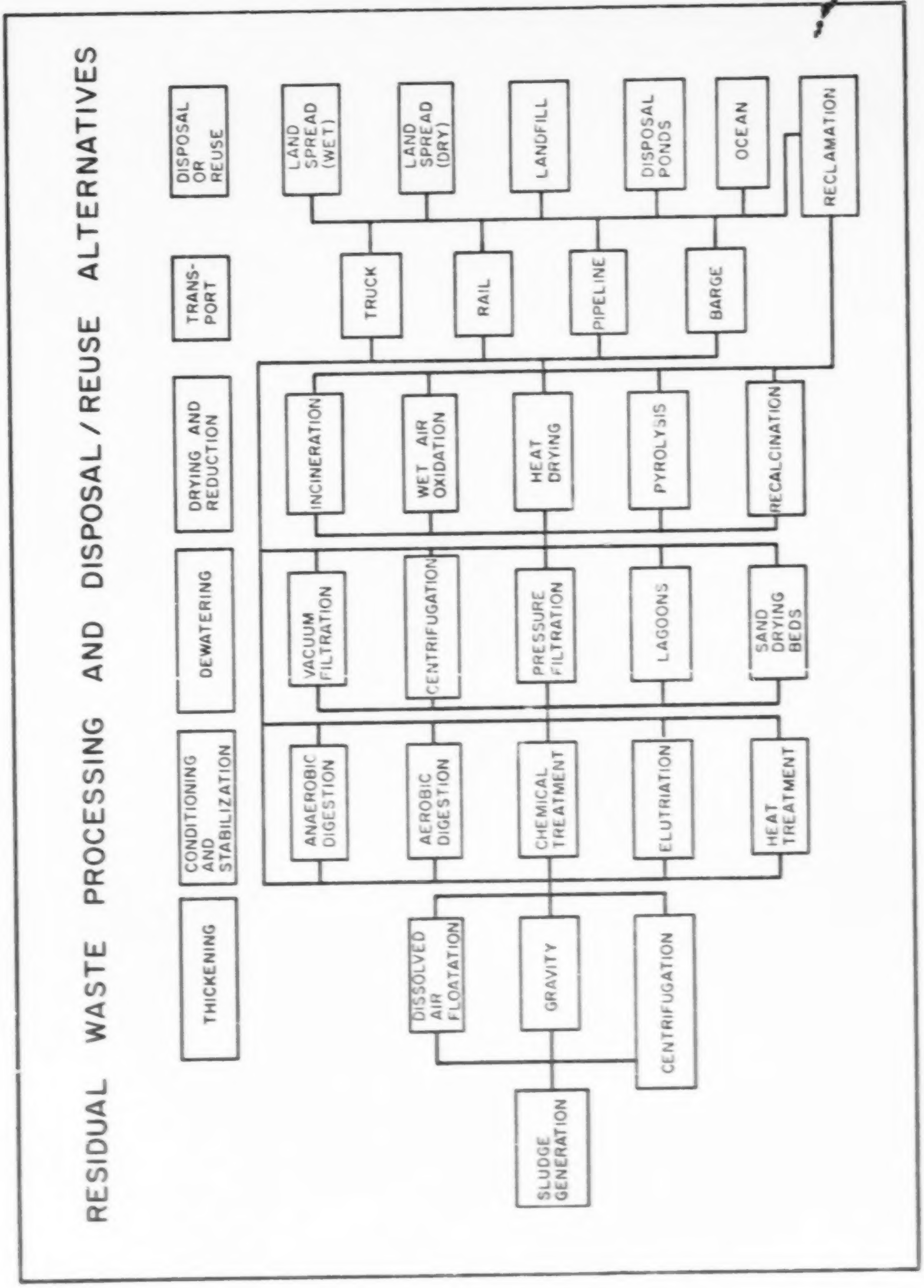
The purpose of the remaining sections of this Chapter is to provide to 208 planning staffs a framework within which reasonable residual waste disposal and/or reuse alternatives can be chosen and evaluated in a systematic manner, utilizing information supplied in this report, guidelines issued by the Environmental Protection Agency, and previous reports which can be obtained for use by the planning agency.

SELECTION OF ALTERNATIVE RESIDUAL WASTE HANDLING PROCESSES

Previous Chapters of this report have discussed the individual elements of residual waste generation sources, means of residual waste treatment and treatment and transport, and methods of residual waste disposal and/or reuse. Figure VII-1 indicates the pathways in which these elements relate to one another. It becomes obvious from this figure that there are numerous methods by which residual wastes may be treated, transported, and disposed or reused. Figure VII-2 indicates the pathways most likely to occur, both in terms of the most commonly employed means of wastewater treatment and sludge handling and disposal as well as the compatability and reliability of process selection and sequencing. More detailed information on the individual process shown in Figure VII-2 may be found in Chapters III (for sludge producing unit processes), Chapter IV (for sludge handling unit processes), and Chapter V (for transport methods). Table VII-1 indicates the description of the pathway elements.

Using Figure VII-2, the planner can select the known wastewater treatment processes and then follow the pathways indicated to obtain numerous sludge handling options. As mentioned in Chapter II, this is the equivalent

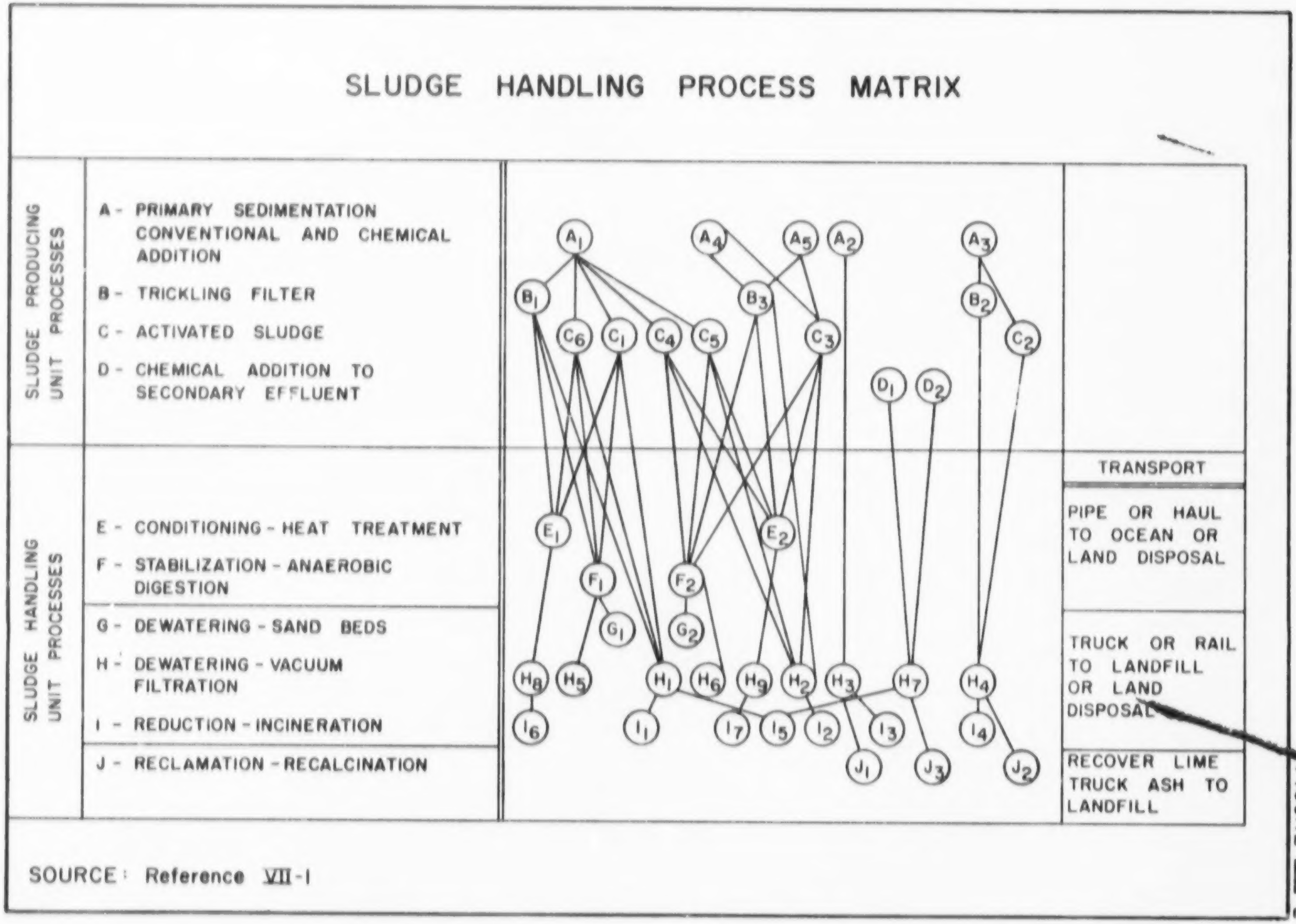
FIGURE VII-1


RESIDUAL WASTE PROCESSING AND DISPOSAL / REUSE ALTERNATIVES

THICKENING
CONDITIONING AND STABILIZATION
DEWATERING
DRYING AND REDUCTION
TRANS-PORT
DISPOSAL OR REUSE
SLUDGE GENERATION
DISSOLVED AIR FLOATATION
GRAVITY
CENTRIFUGATION
ANAEROBIC DIGESTION
AEROBIC DIGESTION
CHEMICAL TREATMENT
ELUTRIATION
HEAT TREATMENT
VACUUM FILTRATION
CENTRIFUGATION
PRESSURE FILTRATION
LAGOONS
SAND DRYING BEDS
INCINERATION
WET AIR OXIDATION
HEAT DRYING
PYROLYSIS
RECALCINATION
TRUCK
RAIL
PIPELINE
BARGE
LAND SPREAD (WET)
LAND SPREAD (DRY)
LANDFILL
DISPOSAL PONDS
OCEAN
RECLAMATION

FIGURE VII-2

SLUDGE HANDLING PROCESS MATRIX


SLUDGE PRODUCING UNIT PROCESSES
A - PRIMARY SEDIMENTATION CONVENTIONAL AND CHEMICAL ADDITION
B - TRICKLING FILTER
C - ACTIVATED SLUDGE
D - CHEMICAL ADDITION TO SECONDARY EFFLUENT
SLUDGE HANDLING UNIT PROCESSES
E - CONDITIONING - HEAT TREATMENT
F - STABILIZATION - ANAEROBIC DIGESTION
G - DEWATERING - SAND BEDS
H - DEWATERING - VACUUM FILTRATION
I - REDUCTION - INCINERATION
J - RECLAMATION - RECALCINATION
A1
A4
A5
A2
A3
B1
B3
B2
C6
C1
C4
C5
C3
C2
D1
D2
E1
E2
F1
F2
G1
G2
H8
H5
H1
H6
H9
H2
H3
H7
H4
I6
I1
I7
I5
I2
I3
I4
J1
J3
J2
TRANSPORT
PIPE OR HAUL TO OCEAN OR LAND DISPOSAL
TRUCK OR RAIL TO LANDFILL OR LAND DISPOSAL
RECOVER LIME TRUCK ASH TO LANDFILL

SOURCE: Reference VII-1

TABLE VII-1

DESCRIPTION OF PATHWAY ELEMENTS

Sludge-Producing Unit Processes (see Ch. III for greater detail)

A. Primary Sedimentation
  - A-1 Conventional
  - A-2 Two-State Lime Addition
  - A-3 Single Stage Lime Addition
  - A-4 Alum Addition
  - A-5 $FeCl_3$ Addition

B. Trickling Filter
  - B-1 Influent: Effluent from A-1
  - B-2 Influent: Effluent from A-3
  - B-3 Influent: Effluent from A-4 or A-5

C. Activated Sludge
  - C-1 Coventional
    Influent: Effluent from A-1
  - C-2 Conventional
    Influent: Effluent from A-3
  - C-3 Conventional
    Influent: Effluent from A-4 or A-5
  - C-4 Alum Addition
    Influent: Effluent from A-1
  - C-5 $FeCl_3$ Addition
    Influent: Effluent from A-1
  - C-6 High Rate
    Influent: Effluent from A-1

D. Two-Stage Tertiary Lime Treatment
  - D-1 Influent: Effluent from B-1
  - D-2 Influent: Effluent from C-1

Sludge Handling Unit Processes (see Ch. IV for greater detail)

E. Heat Treatment
  - E-1 Sludge Influent: Generated from A-1+B-1, C-1 or C-6
  - E-2 Sludge Influent: Generated from A-1+C-4 or C-5, A-4+B-3 or C-3, A-5+B-3 or C-3

F. Anaerobic Digestion
  - F-1 Sludge Influent: Generated from A-1+B-1, C-1 or C-6
  - F-2 Sludge Influent: Generated from A-1+C-4, or C-5 A-4+B-3 or C-3, A-5+B-3 or C-3

G. Sand Drying Beds
  - G-1 Sludge Influent: Effluent Sludge from F-1
  - G-2 Sludge Influent: Effluent Sludge form F-2

TABLE VII-1

(Continued)

H. Dewatering - Vacuum Filtration
- H-1 Sludge Influent: Generated from A-1+B-1, C-1 or C-6
- H-2 Sludge Influent: Generated from A-1+C-4 or C-5
A-4+B-3 or C-3, A-5+B-3 or C-3
- H-3 Sludge Influent: Generated from A-2
- H-4 Sludge Influent: Generated from A-3+B-2 or C-2
- H-5 Sludge Influent: Effluent Sludge from P-1
- H-6 Sludge Influent: Effluent Sludge from P-2
- H-7 Sludge Influent: Generated from D-1 or D-2
- H-8 Sludge Influent: Effluent Sludge from E-1
- H-9 Sludge Influent: Effluent Sludge from E-2

I. Incineration - Multiple Hearth
- I-1 Influent Sludge: Effluent Sludge from H-1
- I-2 Influent Sludge: Effluent Sludge from H-2
- I-3 Influent Sludge: Effluent Sludge from H-3
- I-4 Influent Sludge: Effluent Sludge from H-4
- I-5* Influent Sludge: Effluent Sludge from H-7+H-1
- P-6 Influent Sludge: Effluent Sludge from H-8
- P-7 Influent Sludge: Effluent Sludge from H-9

J. Recalcination (includes chemical storage and feeding)
- J-1 Sludge Influent: Effluent Sludge from H-3
- J-2 Sludge Influent: Effluent Sludge from H-4
- J-3 Sludge Influent: Effluent Sludge from H-7

Note: Use pathway from H-1 to I-5
only when D-1 or D-2 is included
in the complete system.

Source: Ref. VII-1

of the first situation, namely that a wastewater treatment facility (or facilities) already exists. Similarly, if certain sludge disposal options (as discussed in Chapter VI) appear the most suitable for use in the 208 planning area, the planner can enter Figure VII-2 at the bottom and follow the pathways back to various wastewater treatment options. Thus, the second situation as described above and discussed in Chapter II can also be investigated.

EVALUATION CRITERIA AND CONSTRAINTS OF ALTERNATIVE RESIDUAL WASTE HANDLING AND DISPOSAL/REUSE PLANS

Guidelines for the development of overall 208 plans have indicated a variety of considerations which must be addressed in the evaluation of alternative plans (Ref. VI-2). These considerations are noted in Table VII-2. Guidelines for the preparation of environmental impact statements for 208 plans have also been developed (Ref. VII-3). A review of these guidelines and information presented in previous Chapters indicates that four groups of factors; namely, economics, environmental effects, performance, and feasibility, will be of major significance in the evaluation and comparison of residual waste management alternatives. Table VII-3 indicates a sludge (residual waste) disposal evaluation matrix which considers these factors.

Cost estimates included in the matrix can be developed objectively for each sludge disposal alternative; non-monetary considerations listed are to be rated descriptively, using terminology such as that suggested later in this section together with whatever summary quantitative information can be provided. In the remainder of this section, each of the evaluation parameters to be considered is elucidated, including typical concerns and requirements of management of the 208 plan with regard to sludge handling and disposal.

Economic factors of capital costs, operating costs, and reclamation revenues are objective evaluations which can be made in a straightforward manner for each sludge disposal alternative. The following sections discuss the parameters mentioned above in more detail including typical concerns and requirements of the management of the 208 plan with regard to sludge handling and disposal.

Economic Parameters

Cost estimates of the residual waste disposal management alternatives include capital costs, annual costs of borrowed funds, and the annual cost of operating and maintaining the system. Credited against these costs would be revenues from direct sale of secondary resources created by the residual waste treatment and/or disposal processes. Reclaimed chemicals such as recalcined lime, methane gas generated from anaerobic digesters and used as a supplemental fuel source, heat generated from incinerators and used for sludge drying or high-rate anaerobic digesters, digested sludge used as a fertilizer or soil conditioner, and revenues from the sale of crops grown on reclaimed lands are representative examples of such revenues. All cost estimates would be compatible with the Federal Pollution Control Act Amendments of 1972, Title 40 - Protection of the Environment, Chapter 1, Part 35, Appendix A - Cost-Effectiveness Analysis. The guidelines furnished in the cost-effectiveness analysis relate to the definitions of service life of land, structures, process equipment, and auxiliary equipment and the elements of cost including the applicable discount rate to be

TABLE VII-2

COSTS AND EFFECTS CONSIDERATIONS OF ALTERNATIVE AREAWIDE PLANS

Significant Effects

1. Water Quality Goals
    - a. Contribution to goals and objectives of the Act.
    - b. Contributions to other water-related goals of the planning area
2. Technical Reliability
    - a. Frequency of plant upsets
    - b. Frequency of spills
    - c. Frequency and effects of combined sewer overflows
    - d. Nonpoint source control
    - e. Regional availability of skilled manpower for treatment plant operation and monitoring
3. Monetary Costs
    - a. Capital costs including discounted deferred costs
        - (1) public
        - (2) private
        - (3) total
    - b. Operation, Maintenance, and Replacement Costs
        - (1) public
        - (2) private
        - (3) total
    - c. Net revenue (public)
    - d. Overhead and plan management

TABLE VII-2

(Continued)

- e. Total average annual costs
    - (1) public
    - (2) private
    - (3) total

4. Environmental Effects
    - a. Hydrology (surface and groundwater)
        - (1) water quality
        - (2) water quantity
        - (3) water quality and quantity problems
        - (4) water uses
        - (5) flood hazards
    - b. Biology
        - (1) rare and endangered species
        - (2) wildlife habitats
    - c. Air quality
    - d. Land
        - (1) change in land uses
        - (2) land use planning and controls
        - (3) amount, type and intensity of growth (relate to 208 land use plan)
        - (4) soil erosion damage
        - (5) significant environmentally sensitive areas

TABLE VII-2

(Continued)

- e. Wastewater management resources
    - (1) energy (power)
    - (2) chemicals
    - (3) land commitment for planned features
- 5. Social and Economic Effects
    - a. Population changes (5-, 10-, and 20-year projections)
    - b. Changes in economic activity where appropriate
        - (1) income per capita
        - (2) agriculture
        - (3) mining
        - (4) manufacturing
        - (5) services
    - c. Dislocation of individuals, businesses, or public services
    - d. Impact on other local, state, and federal projects having major interaction with proposed water quality actions
    - e. Public health
    - f. Aesthetics
        - (1) recreational accessibility and activities
        - (2) unique archeological, historical, scientific, and cultural areas
        - (3) noise pollution
- 6. Implementation Feasibility
    - a. Legal authority

TABLE VII-2

(Continued)

   - b. Financial capacity
   - c. Practicability
   - d. Coordinative capacity
   - e. Public accountability

7. Public Acceptability

used in the evaluation and selection of alternatives (see Appendix A). Additional economic considerations applicable to residual waste disposal alternative selection are presented in Reference VII-2. Procedures for calculating present worth and annual cost may be found in Reference VII-4.

Information regarding capital and operation and maintenance costs for residual waste processing, transport, and ultimate disposal is noted in Chapters IV, V, and VI of this report. This information, used in conjunction with the sludge handling process matrix (see Figure VII-2), will provide the planner with a means by which reasonable sludge handling and disposal systems can be combined and evaluated on a cost-effective basis using the guidelines referred to above.

The planning agency should also consider the regional economy and indigenous resources of the area when considering such factors as cost of labor, materials, fuels, transportation, and their availability within the region. There should be joint plan review between the 208 planning agency and existing regional agencies such as those acting as a clearinghouse for the A-95 review process. This would prevent duplication of planning efforts and provide an integration of urban growth and transportation plans with the regional 208 plans. It is obvious that information on the projected population growth, its characteristics and mix, and the transportation systems to move the population and required resources will greatly assist the 208 planning agency in determining the projected tax base from which revenues could be derived for constructing, operating, and monitoring residual waste disposal systems.

Environmental Parameters

The processing and disposal of residual wastes may influence environmental quality in many ways and may generate secondary effects beyond the

TABLE VII-3

ALTERNATIVES EVALUATION MATRIX

PARAMETERS		ALTERNATIVE	ALTERNATIVE	ALTERNATIVE	ALTERNATIVE
ECONOMICS	CAPITAL COST				
	ANNUAL CAPITAL AMORTIZATION				
	O. AND M. COST				
	RECLAMATION REVENUE				
	PRESENT WORTH				
		RATING	RATING	RATING	RATING
ENVIRONMENTAL FACTORS	WATER QUALITY				
	AIR QUALITY				
	LAND QUALITY				
	FLORA AND FAUNA				
	AESTHETICS				
	PUBLIC HEALTH				
	COMMUNITY IMPACT				
	RESOURCE CONSERVATION				
FEASIBILITY	FINANCIAL FEASIBILITY				
	PUBLIC ACCEPTABILITY				
	LAND USE COMPATABILITY				
	EASE OF IMPLEMENTATION				
PERFORMANCE	SYSTEM EFFECTIVENESS				
	RELIABILITY				
	ADAPTABILITY				
	CALAMITY RESISTANCE				
	PERMANENCE				

immediate receiving environment. Several major environmental factors such as water, air, and land quality; biology; aesthetics; public health; community impacts; and resource conservation have been investigated in this report. The planner is referred to Chapter VI for an in-depth and detailed evaluation of these factors for the various ultimate disposal or reuse methods. The review of the environmental parameters discussed here is broad, general, and intended to provide the planner with an overview of the major concerns within the environmental factors. Means of implementing programs to address these concerns by the management agency during the operation of the 208 plan programs are also highlighted.

Water

Evaluation of the effects of residual waste handling and disposal should consider both fresh surface and ground water as well as marine waters. Relative values of fresh versus marine waters are difficult to establish. For all purposes short of potable water supplies, the two have similar uses such as recreation, fisheries, and transportation. Indeed, even for special coastal municipalities using or considering desalting of saline waters to supply or augment potable waters, marine and fresh waters both may serve as sources of potable water. In the preparation of 208 plans, the planning agency must provide coordination between water supply and wastewater treatment agencies' plans to insure that disposal of residual wastes from water treatment plants into municipal sewers does not adversely affect wastewater treatment and vice versa. The planning agency should act as a review body for water and wastewater treatment plans to insure compatibility and to promote and encourage joint-residual waste handling and resource recovery projects. Power to act as a review body will preferably be an expressed power enacted through enabling state legislation. Acting as a plan review body, the agency could (1) encourage the water supply agencies to actively pursue programs to reduce household water consumption through pricing mechanisms and plumbing code revisions, (2) encourage installation of water-saving devices (e.g., pressure-reducing valves, shallow-trap toilets, flow-restricting showerheads, and others), and (3) encourage adoption of wastewater treatment technologies which produce less residual wastes in the treatment process. Likewise, the agency could encourage combining water treatment plant residual wastes with wastewaters for further processing and disposal in wastewater treatment facilities if it were technologically feasible and environmentally sound.

Obviously, the planning agency must insure that the 208 plans developed will meet existing Federal and State standards for water quality. Where state standards do not directly address residual waste processing, handling, and disposal with regard to the protection of state waters, the management agency should either seek to possess statutory authority to promulgate and enforce such standards or provide mechanisms of coordination with other state agencies promulgating and enforcing such standards. A mechanism for coordination which may be used is a permit system administered by the management agency for constructing, operating, and/or monitoring residual waste treatment, transport, and disposal systems which allows state or local agencies concerned with public health and sanitation, water quality, and transportation safety and comment on and review for approval applications for such permits.

Air

The handling and treatment of residual wastes can result in volatilization of compounds to the atmosphere and even possible direct discharge to the atmosphere via off-gases from incinerators, anaerobic digesters, and recalcination kilns. It is also possible for the residual waste disposal site to present problems of air pollution such as gas generation from sanitary landfills and wind-blown aerosols from land reclamation/sludge recycling projects. As with the protection of the aquatic environment, the management agency should seek authority to promulgate and enforce air quality or emissions standards specific to residual waste handling and disposal if such standards do not already exist. Likewise, the management agency may provide through a permit system the approval of local and state agencies responsible for maintaining and monitoring air quality. Air quality is measured by standard parameters such as particulates, sulfur dioxide, and oxides of nitrogen and, as such, both the degree of intensity and extent of the affected area for these parameters must be considered in the alternative evaluations.

Land

Protection of land quality goes beyond the protection of land fertility and the growth of acceptable crops. If the method of disposal or reclamation of residual wastes involves land application, nearby land use and growth patterns must be protected and assured. Local, areawide, and State agencies concerned with land development and urban/rural growth plans should play an active part in the preparation of regional ultimate disposal and land reclamation/sludge recycle plans, from identification of suitable land sites to assistance in developing appropriate monitoring program and permitting procedures. Condemnation rights and legal liability for incoming and outgoing transport systems such as pipelines and rail and truck routes must be assured either by the management agency itself or in cooperation with local agencies. As with all other disposal sites, sanitary landfills accepting residual wastes or projects involving land reclamation/sludge recycling must provide controlled access to only properly authorized personnel. Where projects involving the growing and selling of crops on reclaimed lands using sludges from municipal wastewater treatment plants are proposed by the planning agency, the management agency should require approval by the various agricultural and public health departments before permitting the growth of food crops. If the regional planning agency proposes to sell residual wastes to the nearby farming community for use as a fertilizer or soil conditioner, the management agency must assure, possibly through a permit system, that the farm operation uses the residual wastes under proper health conditions.

Flora and Fauna

Flora and fauna are inextricably linked through various tropic levels in all ecosystems. Areas of concern include trees, shrubs, grasses, crops, aquatic plants, endangered species, birds, land and water animals, and insects. A particular sludge disposal alternative may affect, either beneficially or adversely, any or all of these elements. Species diversity and population within that species, both with and without a particular sludge management alternative, must be considered by the planning agency.

Aesthetics

Aesthetics standards are largely results of prior exposure and conditioning, varying widely between individuals. Visual and auditory clarity and composition impact upon one's perception of a "clean and enjoyable" environment. Architectural design to blend with local surroundings and noise levels, particularly in transport and disposal must be considered and adverse impacts kept to a minimum.

Public Health

Public health aspects of a sludge disposal alternative consider the risks of transmission of diseases or toxic substances to the public. Many of the concerns in this area are included in the evaluation of water, land, and air quality. Additional concerns may also include insect or rodent infestation through the use of a particular sludge disposal alternative or the protection of workers under adverse or potentially dangerous working conditions.

Community Impact

Communities may be affected in a variety of ways under different sludge disposal alternatives. For example, removal of an ineffective sludge handling procedure in a community wastewater treatment facility and consolidation in a central treatment plant may enhance outlying community property values. However, added truck traffic with its accompanying noise, dust, and exhaust emissions may place undue strains upon local street traffic and visually impair local atmosphere and harmony.

Resource Conservation

Resource conservation recognizes the need to preserve limited and diminishing resources. Alternatives which may not be more economical but do provide resource reclamation may be chosen by the public, albeit at a higher cost (premium) for the very fact of resource reclamation. Short-term impacts such as higher costs must be weighed against the long-term effects of conserving limited resources.

Table VII-4 provides the planner with a means of assessing the relative impacts of alternative residual waste plans upon the factors discussed above.

Feasibility Parameters

Financial Feasibility

It is probable that future sludge handling and disposal systems will involve greater costs, both capital and operating, than previous systems. If the alternative system imposes too high a financial burden upon the management agency, then the alternative is not feasible. It is recognized that different sludge management systems may be eligible for different portions of Federal, State, and local funding. Therefore, the grant eligibility of the system as a whole will help determine its overall rating. Likewise, a larger portion required of local funding may place strains upon local governments' ability to raise the necessary revenues.

The management agency will have statutory authority to accept and manage Federal and State grant monies, raise revenues, and incur short- and long-term indebtedness. If the agency were to consider assuming the financial responsibilities of constructing, operating, and monitoring various regional disposal sites, it should also have powers to finance general obligation bonds or system-user charges sufficient to recover the costs incurred. Such financial power would then serve as a control mechanism in combination with standards promulgated by the agency pertaining to types, volumes, and characteristics of residual wastes to be handled and disposed by the agency. If local areas or municipalities are allowed to construct, operate, and monitor disposal sites or land reclamation/sludge recycling projects, surety bonds could be required by the management agency to insure adherence to standards and regulations and that, upon abandonment of the site or completion of land reclamation, the site would be available for productive and safe community use.

Public Acceptability

Strong opposition at a local level may arise due to potential increases in water and sewer rates or special assessments. An effective public education program would then be necessary to insure implementation of the selected alternative. Likewise, this public education process, particularly during the 208 plan review process called for in the 208 guidelines (Ref. VII-2), will provide a forum in which public attitudes, if adverse to sludge handling and disposal alternatives proposed by the planning agency, can be modified by an in-depth review of the benefits accruing to the public by adoption of the preferred plan.

TABLE VII-4

IMPACTS, MEASURED FROM MOST DESIRABLE TO LEAST DESIRABLE, ON ENVIRONMENTAL FACTORS TO BE CONSIDERED IN PLANNING FOR THE ULTIMATE DISPOSAL OF RESIDUAL WASTES

WATER QUALITY	AIR QUALITY	LAND QUALITY	AESTHETICS
Significant improvement in all waters, fresh or marine	Improves basin-wide air quality, directly and indirectly	Notably increases soil productivity and use options	Greatly improves aesthetic qualities and provides for future
	Substantially lowers local levels of most air pollutants	Temporarily increases soil productivity and use options	
Significant localized improvement in water quality	Substantially lowers local levels of some air pollutants		Promotes aesthetic quality in localized areas
		Increases soil productivity or use options	
Indirectly causes a slight improvement in water quality	Results in slight decreases in some air pollutants		Compatible with present aesthetic qualities
No changes in any water quality	No changes in air quality	No changes in land quality	No changes in present aesthetic quality
Indirectly causes slight degradation	Produces slight increases in odors or dust		
		Decreases soil productivity or use options	Degradation of aesthetic qualities in some local areas
Water quality degraded in localized areas	Produces substantial increases in several air pollutants		
Substantial degradation of fresh or marine waters	Significantly degrades local air quality	Ultimately limits soil productivity and use options	Some loss of areas with desirable aesthetic qualities
Extreme degradation of potable water supplies	Degrades basin-wide air quality	Substantially limits soil productivity and use options	Totally incompatible with desired aesthetic standards

TABLE VII-4

(Continued)

PUBLIC HEALTH	COMMUNITY IMPACT	RESOURCE CONSERVATION
Substantially reduces threat to public health	Promotes or improves environment of community	Promotes beneficial use of sludge and reduces usage of natural reresources
	Produces increase in community property values	
Reduces potential of harm to public health		Substantially reduces usage of resources for sludge disposal
	Reduces nuisance effects of present situation in community	
		Consumes fewer primary resources with no increas in secondary resource production
No change in public health involvement	No change in social or physical elements of the community	Maintains present level of energy and materials resource usage
Increases potential of harm to public health	Increases noise or odor levels in community	
		Increases primary resource consumption and decreases secondary resource production
	Substantially increases traffic or lowers property values in community	
Positively increases threat to public health	Involves displacement of residents from community	Consumes greater quantities of resources with no secondary production

Land Use Compatibility

Land use compatibility insures compliance with existing and future land use plans. The alternative evaluations must consider preservation of open spaces, areas of scenic beauty, flood plain usage, zoning ordinances, and use of buffer zones around treatment systems and land disposal/recycle areas. The investigation of land use compatibility must be addressed thoroughly in the plan review process, particularly under the environmental factor of quality.

Ease of Implementation

The ease of implementation considers the degree of difficulty in working within current and projected legislative mandates and regulations. Major reorganization of existing agencies including their responsibilities as well as requirements for additional legislative and regulatory powers will severely hamper the utility of a sludge management alternative.

As mentioned under public acceptability, necessary changes in local ordinances or State legislation to allow implementation of the preferred sludge handling and disposal option will be partly accomplished by providing to the public, and hence to elected local and State officials, the sound rational for the required changes. The management agency, during the 208 plan implementation process, may also be given authority to appear before the requisite local and State agencies to request changes in ordinances or regulations governing sludge handling and disposal management. The ease with which these change processes can and will occur must be considered during the planning process.

Table VII-5 provides the planner with a means of assessing the relative impacts of alternative residual waste plans upon the feasibility parameters discussed above.

Performance Parameters

Effectiveness and Reliability

A residual waste treatment and disposal system must be reliable, adaptable and provide resistance against calamity and failure. The reliability of a residual waste treatment and disposal system varies depending upon the processes employed. For example, a stable aerobic sludge digestion process has a higher reliability than anaerobic digestion which is subject to longer-term upsets and associated down times from toxic materials or poor process control. Similarly, complex mechanical treatment systems such as wet air oxidation have an inherently lower reliability than digestion processes because of greater stresses on the components of the process and a higher probability of mechanical failure. Systems with duplicate components on standby may provide greater reliability but will suffer in an economic comparison with other systems possibly not as reliable. Relatively new and untried processes such as pyrolysis would

TABLE VII-5

IMPACTS, MEASURED FROM MOST DESIRABLE TO LEAST DESIRABLE, ON FEASIBILITY FACTORS TO BE CONSIDERED IN BASIN PLANNING FOR THE ULTIMATE DISPOSAL OF RESIDUAL WASTES

FINANCIAL FEASIBILITY	PUBLIC ACCEPTABILITY	EASE OF IMPLEMENTATION	LAND USE COMPATABILITY
Readily falls within funding capabilities of responsible agency	Desired by overwhelming majority of the public	Readily implementable by existing agencies within current legislative limits	Compatible with existing land use plans
	Strongly supported by local groups		
	Supported by some local groups		Will require some plan and zoning changes
		Will require minor changes in legislative limits	
Marginally falls within funding capabilities of responsible agency	Public ambivalent toward this system		
	Opposed by some local groups	Will require minor reorganization of agencies	Will require substantial plan and zoning changes
		Will require major changes in legislative limits	
	Strongly opposed by local groups	Will require major reorganization of agencies	
Financing unsupportable by grants and beyond local means	Opposed by overwhelming majority of the public	Exceeds legal limits beyond possibility of changing limits	Totally incompatible with land use plans

receive subjectively a lower rating on reliability since performance data have not been developed on large-scale operating systems.

Adaptability

The severity of system disruption must be considered in the evaluation of sludge disposal alternatives. For example, a break in a sludge pipeline carrying digested sludge to a land disposal system may cause serious, yet localized environmental damage. Alternative transportation such as by truck must be available if the central sludge treatment system does not have storage capacity (i.e., time) sufficient to allow time for pipeline repair. Capability at or near the ultimate disposal site for residual waste storage during down times may also provide an additional alternative.

Calamity Resistance and Performance

It is reasonable to expect that population and environmental changes and developing new processing techniques may result in changed and possibly more restrictive performance criteria. Therefore, a residual waste processing and ultimate disposal system must be able to accommodate possible altered performance and monitoring criteria. In addition, unexpected events such as floods, earthquakes, high winds, and labor disputes can adversely affect an overall residual waste disposal system. The planning agency must provide means by which the disposal system can withstand such events by providing proper long-range planning, design and operating standards, and alternative contingency handling and disposal plans.

Table VII-6 indicates, for those processes shown in Figure VII-2, factors of performance normally considered in selection of wastewater treatment and sludge handling unit processes. A greater degree of these processes and their alternatives is presented in Chapter IV.

Table VII-7 provides the planner with a means of assessing the relative impacts of alternative residual waste plans upon the performance factors discussed above.

TABLE VII-6

FACTORS OTHER THAN COSTS NORMALLY CONSIDERED IN SELECTION OF WASTEWATER TREATMENT AND SLUDGE HANDLING UNIT PROCESSES

	Land Requirements	Adverse Climatic Conditions	Ability to Handle Inlet Flow Variations	Ability to Handle Influent Quality Variations	Industrial Pollutants Affecting Process	Reliability of the Process	Ease of Operation & Maintenance	Occupational Hazards	Air Pollution	Waste Products
A - Primary Sedimentation										
Conventional	Mod.	-*	Fair	Good	Mod.	Good	Very Good	Structures	Odors	Sludges
With Chemicals	Min.	-	Good	Very Good	Max.	Very Good	Good	Chemicals		Sludges
B - Trickling Filters	Max.	Freezing	Good	Fair	Mod.	Very Good	Very Good	Structures	Odors	Sludges
C - Activated Sludge										
Conventional	Mod.	-	Fair	Good	Mod.	Good	Fair	Structures	-	Sludges
With Chemicals	Min.	-	Good	Very Good	Max.	Good	Good	Chemicals	-	Sludges
D - Two-Stage Lime Treatment	Max.	-	Good	Good	Min.	Very Good	Fair	Chemicals	-	Excess
E - Heat Treatment	Mod.	-	Fair	Fair	Min.	Good	Fair	Explosion Gas	Odors	Sludge Filtrate
F - Anaerobic Digestion	Max.	-	Good	Good	Max.	Good	Good	Explosion	-	Sludge, CO_2 Methane
G - Sand Beds	Max.	High Rainfall	Good	Good	Min.	Fair	Very Good	-	Odors	Sludge
H - Dewatering	Min.	-	Fair	Fair	Min.	Good	Good	Chemicals	-	Sludge Filtrate
I - Incineration	Min.	-	Fair	Good	Min.	Very Good	Fair	Explosions	Combustion Products	Ash
J - Recalcination	Mod.	-	Fair	Good	Min.	Good	Fair	Explosions Chemicals	Combustion Products	Ash

-* means none

NOTE: Letters above refer to the alternative process selection matrix shown in Figure VII-2

TABLE VII-7

IMPACTS, MEASURED FROM MOST DESIRABLE TO LEAST DESIRABLE, ON PERMANCE FACTORS TO BE CONSIDERED IN PLANNING FOR THE ULTIMATE DISPOSAL OF RESIDUAL WASTES

SYSTEM EFFECTIVENESS	RELIABILITY	ADAPTABILITY	CALAMITY RESISTANCE	PERMANENCE
Will greatly exceed performance criteria	Will perform reliably 100 percent of the time	Will readily adapt to new processes or performance criteria	Fully functioning in event of earthquake, labor dispute, etc.	System will be adequate for 50-year lifespan of major structures
	Simple system with little mechanical downtime			
			Will remain fully functional and require only minor repairs	
Will exceed performance criteria in several parameters	Complex system with little mechanical downtime			
		Will adapt to some new performance criteria		
Will meet performance criteria		Will adapt to some new processes	Will maintain minimum function and require some repairs	System adequate for immediate planning horizon
	Simple system unproven in full-scale operation		Will cease functions for a very short period of time	
Will fail to meet a few minor criteria	Has been demonstrated to have frequent mechanical problems			
			Will cease function for more than several days	
Will fall substantially short of meeting criteria	Complex system unproven in full-scale operation	Will not adapt to new processes or performance criteria	In event of calamity, will cease function and require major repairs	Interim measure, usable for several years only

CHAPTER VII

REFERENCES

VII-1 *A Guide to the Selection of Cost-Effective Wastewater Treatment Systems*, prepared by Bechtel Incorporated, for the U. S. Environmental Protection Agency, Contract No. 68-01-0973 (May 1973).

VII-2 *Draft Guidelines for Areawide Waste Management Planning for Section 208 of the Federal Water Pollution Control Act Amendments of 1972*, U. S. Environmental Protection Agency (October 1974).

VII-3 *Manual for Preparation of Environmental Impact Statements for Wastewater Treatment Works, Facilities Plans, and 208 Areawide Waste Treatment Management Plans*, Office of Federal Activities, U. S. Environmental Protection Agency (July 1974).

VII-4 *Guidance for Facilities Planning*, U. S. Environmental Protection Agency (January 1974).

CHAPTER VIII

MANAGEMENT OF A CONTROL AND MONITORING PROGRAM

INTRODUCTION

Following adoption of a 208 plan which includes a residual waste control and monitoring program as specified by Sections 208(b)(2)(J), 208(b)(2)(K), and 208(c)(2), the 208 management agency must provide for a coordinated control and monitoring program. Many of the concerns that must be addressed by the management agency have been covered in Chapter VII. In complying with Section 208(c)(2) of the Act, the legal problems, institutional models, and regulatory mechanisms pertinent to the management agency have been fully addressed elsewhere (Ref. VIII-1). The purpose of the remaining sections of this chapter is to provide the management agency with suggested elements of a control and monitoring program for the ultimate disposal of residual wastes. The specifics of these elements for each ultimate disposal method were discussed in Chapter VI.

CONTROL PROGRAM

Depending on delegation or statutory powers of the control program, adherence to regulations may be elicited through voluntary compliance by persuasion (from proffering financial and/or technical assistance and public pressure) or by direct legal requirement. In maintaining good relations between the waste disposer and the management agency, persuasion is most commonly employed with the possibility of public pressure and legal action existing as a form of unarticulated intimidation. Utilization of a particular disposal method may be governed by a permit and license program, environmental (land, air, and water) quality standards, a land use priority system, or purchase of disposal rights. More than one regulatory technique can be used in conjunction to complement each other.

Permit System

A permit is a written document granted by the management agency to allow the permit holder to engage in a particular activity. While a fee is usually assessed, the primary objective of the permit is to obligate the holder to comply with stipulations which are regulatory in nature. The stipulations assure:

(1) limiting the number of waste disposers utilizing a particular method;

(2) regulating quality/quantity of disposed waste to insure little infringemet upon beneficial use of natural resources;

(3) compliance with monitoring and inspection requirements;

(4) obligation to waste pretreatment before disposal (depending on quality/quantity characteristics of the waste);

(5) adequacy of waste conveyance; and

(6) competency of operator through requirement of operator licensing.

Given waste characteristics, the disposal site might be formally classified to accept a particular waste. Thus, a permit may be granted to dispose of a waste only at disposal sites of a certain class. If the waste is changed in character after disposal has commenced, then a new permit may be required. Permit stipulations might alter if conditions change at the site or if new or significant data is revealed concerning the site.

If non-compliance with permit stipulations occurs and the disposer cannot immediately meet requirements, then a time schedule of compliance may be designed. To insure that the schedule enables compliance at the earliest date, the schedule is periodically reviewed and updated. When significant violations of waste disposal requirements or prohibitions are threatened or violations are occurring, have occurred, or will probably continue to occur, a cease-and-desist order might be issued, if the agency is so empowered. Legal action could result in suspension or revocation of the permit, or a fine and even imprisonment may be levied. Such punishment results from violation of permit stipulations, negligence, incompetence, misconduct, or fraud and deceit in obtaining the permit.

Environmental/Effluent Quality Standards

Various standards establish water, air, or land quality criteria that define limits (usually upper limits) on amounts of physical/chemical/biological parameters. Water quality considerations are:

(1) receiving water standards (e.g., stream standards);

(2) effluent standards (effluent that is discharged to receiving waters from the disposal site); and

(3) pretreatment standards (required of waste before utilizing a particular disposal method).

Standards facilitate the attainment of goals regarding a clean environment by quantifying minimum quality of a clean environment. Quantified stipulations as part of permit qualifications may directly reference relevant standards. In addition to preserving general environmental quality, standards maintain public health and aesthetic values.

Receiving water standards are based on water quality requirements to preserve beneficial uses of the water resource. Water may transport contaminants from a disposal site to contiguous receiving waters. By establishing an acceptable discharge loading from the disposal site, water quality will be maintained commensurate with requirements of all water users (utilization of water resources to receive effluent is a water use). The acceptability of the discharge is determined by the carrying capacity of the receiving waters and relative use of these waters within the matrix of all users concerned. Because existing quality of receiving waters is the result of more than one contributing source, defining the particular source responsible for violating standards is difficult. Enforcement of standards is based on an adequate surveillance program followed by agency investigation if the standards are violated and culminating in voluntary compliance or legal action to reduce contamination from a particular source.

Effluent standards control quality/quantity of effluent water from disposal sites. Standards are sufficiently high to insure that the overall effect of all dischargers on the receiving waters will not infringe upon beneficial uses of the water resource. Criteria can be revised and usually made more stringent if the total number of dischargers increases, creating a pollution problem. Even though stream standards are more efficient in utilizing the full carrying capacity of the receiving waters, pinpointing a standards violator is difficult for enforcement purposes. Effluent at the point of discharge can be directly monitored to indicate violators. However, most disposal sites act as non-point dischargers (see Chapter VI for details of disposal methods) which are difficult to control by any means, including effluent standards. This is usually due to the existence of variable loading magnitudes and the nondiscrete and possibly variable discharge locations. Violation of effluent standards may be discerned by a monitoring and surveillance program. Upon violation, enforcement may lead to voluntary rectification or legal sanctions. The disposal facility may undergo physical or operational modification, or the disposer may be required to alter the incoming residual waste characteristics such that violation will not occur.

Pretreatment of residual waste is to qualitatively/quantitatively transform the waste to a state amenable to disposal by a particular method (see Chapter IV for discussion of such transforms). A management agency would require users of the disposal site to meet standards of residual waste to be disposed. Such standards might be based on operating limitations of the disposal method or on protection of off-site resources. Pretreatment standards may be part of permit stipulations to dispose of waste. Where a permit is granted for a specific, classified disposal site, the standards apply to all of those particular permit holders equally. Enforcement of pretreatment standards, based on monitoring and surveillance, would lead to altering the waste to comply with standards or to cease and desist disposing at the particular site.

Land Use Regulation

By land use control, disposal of residual waste may be regulated by prohibition to or allocation of an area for disposal purposes. This is primarily a control mechanism used in urban or environmentally critical areas, usually by means of a zoning code. Zoning codes deal with environmental quality based on considerations of present and future public health, safety, aesthetics, and general welfare of the community. Critical areas controlled by zoning include shorelines and flood plains which are susceptible to flooding. While zoning codes generally specify what use may or may not be made of a certain area, land use control can exist at a more diffuse level by specifying certain conditions that must be met in using land in a particular manner. This control is exampled by soil conservation districts which are concerned with prevention of soil erosion. Several of the more common waste disposal methods are susceptible to soil erosion (see Chapter VI for additional detail). In consideration of soil erosion, authority exists to regulate construction operations, cultivation methods, cropping programs, and denuding land (e.g., clearing). By possessing such authority, a management agency concerned with control of residual waste disposal can more easily deal with non-point discharges of contaminants. Violations might be corrected by voluntary compliance or legal sanctions.

Disposal Charges

A form of control over waste disposal is to charge monetary payment from users of a particular disposal site. Imposition of the charge would be based primarily on quantity but could also include quality of the residual waste to be disposed. Rather than being allowed to degrade the environment by possessing the financial capability to pay any amount of assessed charges, an upper boundary of waste loading may be established with each user purchasing a loading allotment of the total. This program is designed to induce the disposer to reduce his waste load output. Such reduction is a significant objective in ultimate disposal of residual waste.

MONITORING PROGRAM

A waste disposal site monitoring program is designed to provide information concerning particular constituents of environmental quality. This information is primarily used to indicate compliance with permit stipulations, standards, and other regulatory statements, usually on a comparative basis with background or initial conditions. Such feedback includes inspection of the physical facility, operation and maintenance, quality/quantity of loading, and characteristics of the disposal site and adjacent environment.

Monitoring the Constructed Facility and Operation

Monitoring the disposal structures and operation can be implemented by:

(1) on-site surveillance; and

(2) requirement of written reports by disposal personnel.

On-site surveillance by a management agency requires that direct, technically competent inspection of the facility be made on a periodic or possibly random basis. This requires legal access to the disposal facility and site. Such inspection would indicate:

(1) compliance with construction regulations;

(2) existence of adequate maintenance;

(3) order of written records;

(4) competence of operation;

(5) general compliance with permit stipulations and/or state standards; and

(6) post-operative condition after shutdown.

Written reports by disposal personnel allows a less extensive monitoring program by the management agency but demands a higher level of competency of disposal employees. Greater assurance of accuracy and dependability of the reports would be engendered by requiring an operator's license of the responsible employee. These reports might address the following items at specific points in time:

(1) completion stages of construction;

(2) documentation of impairment in operation;

(3) service and repair of equipment; and

(4) safety record.

Monitoring Parameters of Environmental Concern

Monitoring parameters of environmental concern include quantity/quality aspects of physical, chemical, and biological components in:

(1) residual waste input;

(2) disposal site environment;

(3) effluent from disposal site; and

(4) contiguous areas of critical concern.

Most monitoring is concerned with environmental parameters and requires a greater expenditure of effort than surveillance of disposal structures and operation. Both fields of monitoring can be implemented by management agency personnel, disposal facility employees, or a combination of both. Access to the disposal site by management personnel is essential. When environmental data is collected by employees of the disposal facility (including private contractors), submission of such information should be through a certified laboratory. Most disposal facilities must also directly deal with monitoring areas adjacent to the disposal site that may be of critical concern.

Most parameters of environmental concern are monitored in response to imposed regulations. These parameters include considerations of public health, aesthetics, and community impact. Specific standards governing the parameters may be present in granted permits in independent influent, effluent, or receiving water standards. In addition to providing information concerning fulfillment of legal obligations, monitoring of residual waste input and the disposal site environment aids in operation of the disposal facility.

APPENDIX A

COST EFFECTIVENESS ANALYSIS GUIDELINES

(40 CFR 35 - APPENDIX A)

federal register

Title 40—Protection of the Environment

CHAPTER I—ENVIRONMENTAL PROTECTION AGENCY

SUBCHAPTER D—GRANTS

PART 35—STATE AND LOCAL ASSISTANCE

Appendix A—Cost-Effectiveness Analysis

On July 3, 1973, notice was published in the FEDERAL REGISTER that the Environmental Protection Agency was proposing guidelines on cost-effectiveness analysis pursuant to section 212(2)(c) of the Federal Water Pollution Act Amendments of 1972 (the Act) to be published as appendix A to 40 CFR part 35.

Written comments on the proposed rulemaking were invited and received from interested parties. The Environmental Protection Agency has carefully considered all comments received. No changes were made in the guidelines as earlier proposed. All written comments are on file with the agency.

Effective date.—These regulations shall become effective October 10, 1973.

Dated September 4, 1973.

JOHN QUARLES,
Acting Administrator.

APPENDIX A

COST EFFECTIVENESS ANALYSIS GUIDELINES

a. *Purpose.*—These guidelines provide a basic methodology for determining the most cost-effective waste treatment management system or the most cost-effective component part of any waste treatment management system.

b. *Authority.*—The guidelines contained herein are provided pursuant to section 212(2)(C) of the Federal Water Pollution Control Act Amendments of 1972 (the Act).

c. *Applicability.*—These guidelines apply to the development of plans for and the selection of component parts of a waste treatment management system for which a Federal grant is awarded under 40 CFR, Part 35.

d. *Definitions.*—Definitions of terms used in these guidelines are as follows:

(1) *Waste treatment management system.*—A system used to restore the integrity of the Nation's waters. Waste treatment management system is used synonymously with "treatment works" as defined in 40 CFR, Part 35.905–15.

(2) *Cost-effectiveness analysis.*—An analysis performed to determine which waste treatment management system or component part thereof will result in the minimum total resources costs over time to meet the Federal, State or local requirements.

(3) *Planning period.*—The period over which a waste treatment management system is evaluated for cost-effectiveness. The planning period commences with the initial operation of the system.

(4) *Service life.*—The period of time during which a component of a waste treatment management system will be capable of performing a function.

(5) *Useful life.*—The period of time during which a component of a waste treatment management system will be required to perform a function which is necessary to the system's operation.

e. *Identification, selection and screening of alternatives*—(1) *Identification of alternatives.*—All feasible alternative waste management systems shall be initially identified. These alternatives should include systems discharging to receiving waters, systems using land or subsurface disposal techniques, and systems employing the reuse of wastewater. In identifying alternatives, the possibility of staged development of the system shall be considered.

(2) *Screening of alternatives.*—The identified alternatives shall be systematically screened to define those capable of meeting the applicable Federal, State, and local criteria.

(3) *Selection of alternatives.*—The screened alternatives shall be initially analyzed to determine which systems have cost-effective potential and which should be fully evaluated according to the cost-effectiveness analysis procedures established in these guidelines.

(4) *Extent of effort.*—The extent of effort and the level of sophistication used in the cost-effectiveness analysis should reflect the size and importance of the project.

f. *Cost-Effective analysis procedures*—(1) *Method of Analysis.*—The resources costs shall be evaluated through the use of opportunity costs. For those resources that can be expressed in monetary terms, the interest (discount) rate established in section (f)(5) will be used. Monetary costs shall be calculated in terms of present worth values or equivalent annual values over the planning period as defined in section (f)(2). Nonmonetary factors (e.g., social and environmental) shall be accounted for descriptively in the analysis in order to determine their significance and impact.

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The most cost-effective alternative shall be the waste treatment management system determined from the analysis to have the lowest present worth and/or equivalent annual value without overriding adverse nonmonetary costs and to realize at least identical minimum benefits in terms of applicable Federal, State, and local standards for effluent quality, water quality, water reuse and/or land and subsurface disposal.

(2) *Planning period.*—The planning period for the cost-effectiveness analysis shall be 20 years.

(3) *Elements of cost.*—The costs to be considered shall include the total values of the resources attributable to the waste treatment management system or to one of its component parts. To determine these values, all monies necessary for capital construction costs and operation and maintenance costs shall be identified.

Capital construction costs used in a cost-effectiveness analysis shall include all contractors' costs of construction including overhead and profit; costs of land, relocation, and right-of-way and easement acquisition; design engineering, field exploration, and engineering services during construction; administrative and legal services including costs of bond sales; startup costs such as operator training; and interest during construction. Contingency allowances consistent with the level of complexity and detail of the cost estimates shall be included.

Annual costs for operation and maintenance (including routine replacement of equipment and equipment parts) shall be included in the cost-effectiveness analysis. These costs shall be adequate to ensure effective and dependable operation during the planning period for the system. Annual costs shall be divided between fixed annual costs and costs which would be dependent on the annual quantity of wastewater collected and treated.

(4) *Prices.*—The various components of cost shall be calculated on the basis of market prices prevailing at the time of the cost-effectiveness analysis. Inflation of wages and prices shall not be considered in the analysis. The implied assumption is that all prices involved will tend to change over time by approximately the same percentage. Thus, the results of the cost effectiveness analysis will not be affected by changes in the general level of prices.

Exceptions to the foregoing can be made if their is justification for expecting significant changes in the relative prices of certain items during the planning period. If such cases are identified, the expected change in these prices should be made to reflect their future relative deviation from the general price level.

(5) *Interest (discount) rate.*—A rate of 7 percent per year will be used for the cost-effectiveness analysis until the promulgation of the Water Resources Council's "Proposed Principles and Standards for Planning Water and Related Land Resources." After promulgation of the above regulation, the rate established for water resource projects shall be used for the cost-effectiveness analysis.

(6) *Interest during construction.*—In cases where capital expenditures can be expected to be fairly uniform during the construction period, interest during construction may be calculated as $I \times \frac{1}{2} P \times C$ where:

I = the interest (discount) rate in Section f(5).
P = the construction period in years.
C = the total capital expenditures.

In cases when expenditures will not be uniform, or when the construction period will be greater than three years, interest during construction shall be calculated on a year-by-year basis.

(7) *Service life.*—The service life of treatment works for a cost-effectiveness analysis shall be as follows:

Land	Permanent
Structures (includes plant buildings, concrete process tankage, basins, etc.; sewage collection and conveyance pipelines; lift station structures; tunnels; outfalls)	30–50 years
Process equipment (includes major process equipment such as clarifier mechanism, vacuum filters, etc.; steel process tankage and chemical storage facilities; electrical generating facilities on standby service only).	15–30 years
Auxiliary equipment (includes instruments and control facilities; sewage pumps and electric motors; mechanical equipment such as compressors, aeration systems, centrifuges, chlorinators, etc.; electrical generating facilities on regular service).	10–15 years

Other service life periods will be acceptable when sufficient justification can be provided.

Where a system or a component is for interim service and the anticipated useful life is less than the service life, the useful life shall be substituted for the service life of the facility in the analysis.

(8) *Salvage value.*—Land for treatment works, including land used as part of the treatment process or for ultimate disposal of residues, shall be assumed to have a salvage value at the end of the planning period equal to its prevailing market value at the time of the analysis. Right-of-way easements shall be considered to have a salvage value not greater than the prevailing market value at the time of the analysis.

Structures will be assumed to have a salvage value if there is a use for such structures at the end of the planning period. In this case, salvage value shall be estimated using straightline depreciation during the service life of the treatment works.

For phased additions of process equipment and auxiliary equipment, salvage value at the end of the planning period may be estimated under the same conditions and on the same basis as described above for structures.

When the anticipated useful life of a facility is less than 20 years (for analysis of interim facilities), salvage value can be claimed for equipment where it can be clearly demonstrated that a specific market or reuse opportunity will exist.

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